SR 24 PROJECT
FLOODPLAIN CONSISTENCY REPORT

SR -24/I-82 TO KEYES ROAD
(MP-0.00 TO MP-0.84, MP-1.29 TO MP-130)

OL-3549

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION
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EXECUTIVE SUMMARY (EA READY)

The SR 24/5 Bridge over the Yakima River is experiencing extreme scour problems that threaten a catastrophic failure under flood conditions. Thus the bridge is listed with the Federal Highway Administration as, “scour critical” and in serious need of replacement.

This report analyzes the potential floodplain impacts to the Yakima River system from alternative bridge alignments for the SR 24 Bridge over the Yakima River at Yakima, Washington. In considering project alternatives, local jurisdictional authorities have asked the department to examine floodplain restoration potential associated with project impact analysis. To honor this request, this report also analyzes the extent to which each alternative facilitates or precludes floodplain restoration for environmental and flood safety reasons as is currently being considered by local jurisdictional authorities managing the Yakima River Floodplain. This evaluation and analysis helps to illuminate opportunities to partner with local jurisdictions responsible for flood control activities. These jurisdictions are governed under local, state, and federal regulations regarding development and activities within the floodplain. Floodplain opportunities for this proposed project include:

- Reduction of property loss due to flood events
- Strengthening and support of the local floodplain vision
- Local level input on decisions affecting floodplains
- Long term reduction to existing and future public infrastructure expenditures and funding needs.
- Direct and indirect benefits to related environmental elements in this area

The findings of this report are as follows:

Recent analysis reveals that the reaches encompassing the project area are located in a key transitional area of the Union Gap sub-basin, between down welling zones upstream and upwelling zones downstream. Furthermore, the project is located where the levee protection afforded by existing system is reduced from 100-year event protection to a five to twenty five year level of protection downstream of the existing alignment. The area is also the location of heightened stream power that partially drives both restoratives potential and flood risk. As such both habitat concerns and flood safety considerations are of extreme importance.

Both a Northern and Southern alternative alignment facilitate roughly the same level of potential floodplain restoration because in either case, the same geomorphic (Blue Slough) and topographic (Keyes Road fill prism) features delineate the logical locations for set back levees facilitating floodplain restoration. Between the two alignments, a bridge built on a Southern alignment has fewer new floodplain impacts in terms of new fill placement, and direct (right-of-way) impact to private lands and structures within the floodplain. All of the Northern alignment would be placed on new floodplain fill. The total estimated footprint of new fill in the floodplain for the Northern alignment is approximately 24.61 acres. Conversely, the Southern alignment would require a 16.29-acre footprint of fill in the floodplain. In addition, about half of this footprint is already occupied with the existing SR 24 road prism and does not represent a new footprint, thus the new floodplain fill footprint estimate for a Southern alternative with a longer span is approximately 8.15 acres. The obvious conclusion is that the impact for the Southern

alignment in terms of new floodplain fill is considerably less that that of the Northern alignment. The argument could be made that in a Northern alignment was constructed, then the existing fill along the southern alignment could be removed. While this could potentially occur, such an action would add to the cost of the project, and only include removing fill where existing property access was not an issue. In addition, the impact in the old right of way from years of soil compaction would hamper restoration of floodplain functions such as hyporheic flow, channel migration, and aquifer recharge for years to come unless normative conditions were restored through excavation and scarification of the substrate once the fill is removed.
The proposed right of way for the north alternative would go through several parcels of private property and directly impacts at least twelve principal structures within the proposed route. An additional five to eight structures may also be affected due to close proximity to the proposed right of way.
By comparison, the Southern Alternatives have relatively few direct impacts on existing private structures, but follows the existing right- of- way, which can be expanded into currently unoccupied areas of the floodplain. Thus the socioeconomic impacts, hardships, and controversy associated with condemnation of directly impacted property is largely avoided.

During the preparation of this report, the Northern alignment was eliminated from further consideration as a NEPA alternative due to environmental and socio-economic impacts. After analysis of the north alternative, it became increasingly apparent that the North Alignment would create significant impacts to both natural and human environments within the project area. The north alternative adversely affected a number of additional waterways, wetlands, established recreational areas, and existing residential home sites in the area. Specifically, the north alignment included disproportionate impacts on relatively undisturbed human communities, sensitive environmental resources, Section 4(f) resource lands, and required significant right- of-way acquisition.

As stated above, this analysis found that essentially the same level of potential floodplain restoration through levee setbacks could be achieved with the SR 24 project being constructed along either alignment, the primary factors being the location of potential levee setbacks and the (by necessity) corresponding length of the proposed bridge.

In analyzing potential floodplain restoration, three span ranges were considered; Short 800-1000-feet, Moderate 1200-1600- feet, and Long 1600-2200- feet were considered.

The short span range allows for a minimum level of floodplain restoration south of the existing alignment, however it precludes any floodplain restoration upstream of the project, and would reinforce hydraulic and bedload dis-equilibrium that drives both flood/avulsion risk and habitat degradation.

The Moderate and Long Span ranges both accommodate considerable (Moderate to Maximum potential) floodplain restoration both upstream and downstream of the project, and can thus be justified only as part of a restoration scenario that involves setting back the levees (particularly those on the east bank) for restorative purposes. While formal hydraulic/ hydrologic analyses for a preferred alternative still must be conducted once that alternative has been chosen the hydrologic/hydraulic trends that emerge from this report indicate that either the moderate of long span range options will improve hydraulic, geomorphic, flood storage, and habitat conditions considerably as part of such a scenario.

Because of its location in the middle of the sub basin, the reaches encompassing the project area form a lynch pin in terms of overall floodplain function, particularly with regard to restoration concerns. Lengthening the SR 24 Bridge removes a bottleneck that allows the direct restoration of nearly two hundred acres of floodplain. In addition, opening up the reaches in the project area facilitates the restoration of many times that acreage both upstream and downstream of the project area. Because the project is centrally located, conditions here reverberate throughout the sub-basin. As such, rectifying degraded floodplain processes, sediment transport, hyporheic flow, cut- and -fill alluvial channel formation, water and sediment storage, etc.) in the project area is an essential element of any effort to restore floodplain functions in the Union Gap sub basin. A summary of ranges considered is presented below:

In considering future options for potential restoration of the Yakima River floodplain the key factor is of course the location of the levee system. This determines the size of the channel migration zone the amount of flood storage provided as well as the potential for the creation of connected habitat. As the SR 24 Bridge must span the area of the floodplain encompassed by the levees (the floodway) the location of the levees is a key determinant for the proposed bridge length. Generally, the wider apart the levees are set, the longer the bridge must be in order to span the floodway. This analysis has identified two geomorphic and topographic features that present logical alternatives for levee setback location on the east bank of the river A levee set back to Keyes Road would accommodate a moderate level of floodplain restoration. It has the advantage of utilizing an existing road grade. In addition a setback along this delineation would closely coincide with setback levees proposed by the Central Premix Company for the proposed East Valley Gravel Mine (*David Brown and Associates 2002*). A levee setback to the east bank of Blue Slough would accommodate the maximum potential floodplain restoration without impacting the more populated area Southeast of the project area along Riverside Road. It has the advantage of utilizing the existing geomorphic channel pattern of the Slough to help set a more stable floodplain boundary. In addition a levee setback along this delineation would allow the restoration of Blue Slough as part of the active floodplain, which would greatly improve habitat.

1.1.1 Short Span Bridge

[Approximately 800 to 1000- feet] The obvious advantage of a shorter span is in cost. However a short span precludes most (if not all) potential floodplain restoration. As a key criteria for this analysis is the degree to which a given alternative does or does not preclude floodplain restoration a short span alternative would not be a preferred option as it would reinforce the current channel constriction that has been shown to be at the root of the environmental and flood risk problems. Backwater and scour effects would continue as would the dis-equilibrium in bedload transport both between and within the reaches of the project area. Avulsion risk would continue to increase as the conditions driving it are reinforced. No improvement in flood storage is provided no improvement in hyporheic function is provided. Assuming an active channel width of three hundred feet, a span in the 800-1000- foot range only accommodates 2.6 to3.1 channel widths for potential channel migration.

1.1.2 Moderate Span Bridge

Moderate span bridge would be approximately 1200 to 1600 feet in length. A span of this range would not preclude a moderate level of floodplain restoration by allowing levee setbacks to occur on the East bank of the river. In terms of floodplain function, setting back the levees would reduce channel constriction, backwater effects, water slope and velocity, streampower, and scour. The extent of these reductions would be determined chiefly, by the length of the span and the number of piers required. These improvements in channel and hydraulic conditions will in turn reduce dis-equilibrium in bedload transport both within and between reaches. As a result avulsion risk would decrease. If floodplain restoration accommodated by a span of a moderate range involves filling in the gravel pits south of the existing alignment (which this analysis concludes would be absolutely necessary) then avulsion risk could be greatly reduced. Additional flood storage would be provided and these storage areas would also enhance hyporheic function. Assuming an average active channel width of three hundred feet a moderate range span would accommodate 4 to 5.3 channel widths for potential channel migration

1.1.3 Long Span Bridge

[Approximately 1600 to 2200- feet] In terms of floodplain function, setting back the levees would reduce channel constriction, backwater effects, water slope, and velocity, streampower, and scour. The extent of these reductions would be determined chiefly, by the length of the span and the number of piers required. A long span would tend to reduce erosive forces more than a moderate span. A backwater analysis would be needed to determine the particular effect of a given bridge length. *(see conclusion-modeling recommendations)*. These improvements in channel and hydraulic conditions will in turn reduce dis-equilibrium in bedload transport both within and between reaches. As a result avulsion risk would decrease. If floodplain restoration accommodated by a span of a moderate range involves filling in the gravel pits south of the existing alignment (which this analysis concludes would be absolutely necessary) then avulsion risk could be greatly reduced. Additional flood storage would be provided and these storage areas would also enhance hyporheic function. Assuming an average active channel width of three hundred feet a moderate range span would accommodate 5.3 to 7.3 channel widths for potential channel migration. Floodplain restoration Pros and Cons for each span range are summarized in **Figure 20**.

Restoration Potential Summary Table

Criteria	Unit	Short (800-1000')	Medium (1200-1600')	Long (1600-2200')
Cost	Rank	L	M	H
Erosive forces	Rank	H	M	L
Floodplain Storage Potential	Acres	106	139	196
Floodplain Restoration Potential	Percent	54%	72%	100%
Hyporheic Function	Rank	Min	Mod	Max
Avulsion Risk	Plus/Minus	Increased Risk	Reduced Risk	Reduced Risk
Channel Migration Opportunity	Channel Widths	2-2.6	2.6-4.6	5.3-7.3

Notes:

- Erosive Forces: Estimates the relative level of erosive force (sheer stress, stream power, velocity, etc) reduction anticipated for each span range.
- Avulsion Risk: Assumes restoration of gravel pits to grade and set back of levees on east bank for medium and long span ranges.
- Channel Migration: Numbers represent potential restored floodplain cross section in terms of channel width assuming a minimum average active wetted channel width of 300-feet.
- L= Low, M= Medium, H= High

The main advantage of a Southern Alignment is that it re-uses the existing right-of-way and avoids most (if not all) direct impacts to private residences and natural resources located in the floodplain. In addition it has a smaller new floodplain fill footprint and reduced wetland and other habitat impacts *(McQueary, 2002).*

If drilled shaft pilings are used (as has been proposed), and the west abutment set back to avoid the unstable bank zone identified in the Yakima County Flood Hazard Mitigation Plan, the replacement bridge should not be affected by the greater stream power present at the southern alignment. To the contrary, it is anticipated that lengthening the span to facilitate levee setback will help alleviate the channel and water surface slope conditions that are driving stream power to such an extreme at this location

<u>Mitigation Recommendations</u>

If changing the bridge length and/or alignment is done to facilitate floodplain restoration, a proportional mitigation credit should be developed and enumerated to account for environmental credits to WSDOT as a result of any bridge configuration that facilitates such restoration. This credit should account for all of the habitat specifically identified under the minimum, moderate, and maximum restoration scenarios developed for this analysis, plus a proportion of adjacent floodplain areas where restoration is facilitated due the normalization of floodplain functions within the project area. "The zones of normative function effect," would extend into the reaches both upstream and downstream of the project area that meet a "but for" test for restorative facilitation. For example, restoration of floodplain upstream of the site is permanently precluded if the bridge is not lengthened because of the bottleneck that the short span imposes on the river channel. Therefore, a proportional credit for future restoration in the reach upstream of the project should accrue to WSDOT to offset efforts to facilitate such restoration through lengthening the bridge.

As described in this report, the Yakima functions as a shifting mosaic of interdependent habitat types (wetlands, active channel; side channel riparian, gravel bars, etc.) It can be a challenge to apply the static arithmetic of mitigation ratios based on discreet acreages for habitat type within the inherently dynamic situation of a functioning cut and fill alluvial floodplain. Development of a proportional template for shifting habitat mosaic components may be a more accurate way to quantify restored habitat values and functions and thus enumerate mitigation credits either from a functional, spatial, and/or economic metric. Given the direct and indirect habitat functions/benefits derived under the project alternatives analyzed in this report, the result of actions taken by WSDOT is that the project is self mitigating with a likely subsequent balance of credit based on the amount of credit left after direct project impacts are deducted from total credit derived from the action(s).

The conclusion of the report includes several key technical recommendations regarding floodplain restoration modeling, infrastructure risk assessment, avulsion potential, and hydraulic/hydrologic analysis for bridge design considerations.

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TERMS AND DEFINITIONS

Avulsion - An abrupt shift in stream course resulting in the establishment of a new channel.

Base Flood Elevation (BFE) - A calculated flood depth for an event of a given recurrence interval, usually the 100 year flood.

Contraction Scour - In a channel or at a bridge crossing, Contraction scour involves the removal of material from the bed and banks across all or most of the channel width. This component of scour results from a contraction of the flow area at the bridge (or in a levee constricted channel), which causes an increase in velocity, and sheer stress at the bridge. The contraction can be caused by the bridge, or from the natural or anthropogenic narrowing of a channel (Levees). [Hydraulic Engineering Circular No. 20, FHWA, 1995]

Dike - In most areas of the U.S., an earthen structure built partway across a river for the purpose of maintaining a navigation channel. In other areas the term is used synonymously with levee. [Glossary of Flood Damage Reduction Terms, USACE, 2002]

Federal Emergency Management Agency (FEMA) – A federal agency that regulates federal actions in floodplains.

Floodplain – The level area adjoining a river channel inundated during periods of high flow.

Floodway – The channel of a stream, plus any adjacent floodplain areas, that must be kept free of encroachment in order that the 100-year flood be carried without substantial increases in flood heights. For the purposes of this report, the floodway is that portion of the floodplain lying within the Yakima River Levee system

Hyporheic Zone—the area of saturated interstitial spaces beneath the stream and into the stream banks (floodplain that contains some proportion of both channel (surface) and ground water. Important physiochemical processes occur in the hyporheic zone that perform essential Biological functions supporting the entire range of freshwater aquatic life forms particularly macro invertebrates and salmonids.

Levee - A structure of earth or stone built parallel to a river to protect land from flooding. [Glossary of Flood Damage Reduction Terms, USACE, 2002]

Levee System - A flood protection system, which consists of a levee, or levees, and associated structures, such as closure, and drainage devices, which are constructed and operated in accordance with sound engineering practices. [44CFR59.1, Revised 10/1/00]

Local Scour – Removal of material from around piers, abutments, spurs, and embankments caused by an acceleration of flow and resulting vortices induced by obstructions to the flow. [Hydraulic Engineering Circular No. 20, FHWA, 1995]

Reach- A geomorphic descriptor for a segment of a river or stream-- usually at least two meander bends in length.

Recurrence Interval - The calculated probability that a flood of a given size will occur in a given year for example, a 100-year flood has a calculated one percent probability of occurring each year, whereas a ten-year flood has a ten per cent chance of occurring each year.

ACRONYMS AND ABBREVIATIONS

ac	acre
ACP	Asphalt Concrete Pavements
BA	Biological Assessment
BMP	Best Management Practices
BOR	Bureau of Reclamation
CEA	Cumulative Effects Analysis
CEQ	Counsel on Environmental Quality
cfs	cubic feet per second
CWA	Clean Water Act
EA	Environmental Assessment
EB	East Bound
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
ft	feet
GMA	Growth Management Act
ha	hectares
km	kilometer
LOS	Level of Service
m	meter
MP	Mile post
mph	Miles per hour
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NPDES	National Pollutant and Discharge Elimination System
OHWM	Ordinary High Water Mark
ROW	Right of Way
SCR	South Central Region
SPPP	Spill Prevention Pollution Plan
SWPPP	Storm Water Pollution Prevention Plan
TESCP	Temporary Erosion and Sediment Control Plan
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
WB	West Bound
WSDFW	Washington State Department of Fish & Wildlife
WSDOE	Washington State Department of Ecology
WSDOT	Washington State Department of Transportation

2.0 INTRODUCTION

Background

The SR 24 (24/5) Bridge over the Yakima River has been of concern to the Washington State Department of Transportation (WSDOT) since 1994 when the WSDOT applied for emergency permits to fix extreme scour problems to pier #4 of the existing bridge. The bridge, built in 1957, is approaching its 50th year of use and coming to the end of it designed life and is the only state highway over the Yakima River that connects to the Hanford and Moxee areas to I-82. Additional damage to the bridge piers occurred between 1994 and 1996, in a series of flood events that reached 56,000cfs (February 1996) that brought to bear further stress to bridge components that were not designed to withstand such force. As a result, the bridge is now listed as “scour critical” within the department’s bridge maintenance program and with the FHWA.

The WSDOT began to look into design requirements for the 24/5 Bridge in 1998. Due to the environmental elements involved in the project and a desire by the Washington State Legislature to help streamline environmental permits, the SR 24 project was selected as a “pilot” transportation project by, the Transportation Permit Efficiency and Accountability Committee (TPEAC), under the auspices of the Environmental Permit Streamlining Act RCW 47.06, in May, 2001. As part of the process of applying RCW 47.06 to the SR 24 project, an “IDT” (Inter-Disciplinary Team) made up of resource agency stakeholders, local jurisdictional entities, regulatory agencies, and WSDOT staff reviewed the scope of the floodplain consistency analysis and established a floodplain technical advisory group.

In January 2002, the WSDOT and TPEAC partnered with Yakima County (lead entity for the regional floodplain management) and the Bureau of Reclamation to re-evaluate project alternatives that could be made to facilitate an emerging local vision for floodplain management of the Yakima River that incorporated floodplain restoration involving potential levee set-backs on the east bank as a major component. While potential setbacks are not a specific part of this project, however, the location of levees in a controlled system such as the Yakima and the length of spans that cross it must by definition coincide. Therefore, the length of the span for this project will in large part determine the extent to which floodplain restoration opportunities are facilitated or precluded within the reaches encompassing the project area. In order to incorporate the emerging local vision, the WSDOT has undertaken a Floodplain Consistency Analysis as part of the Environmental Assessment (EA) for the SR 24, I-82 to Keyes Road project.

Project Purpose and Need

Purpose. The Washington State Department of Transportation (WSDOT) proposes to widen the existing State Route (SR) 24 from two lanes to four lanes between the intersection of South 18th Street and Nob Hill Boulevard within the City of Yakima, Washington and Riverside Road, and SR 24 in Yakima County. The purpose of the project includes the replacement of the Yakima River Bridge (24/5). The proposed project termini’s are from MP –0.15 to MP- 1.91.

<u>Need.</u> Traffic congestion and safety provide the greatest need for this project. These problems strand motorists and freight resulting in substantial safety hazards to the traveling public, travel delays and impacts to the local economy. The traveling public and movement of goods remains at risk as long as these problems exist. The risk is expected to increase proportionate to traffic growth.

Traffic volumes on SR 24 have grown through time, at an estimate 4.4% per year. Current volumes are expected to continue to increase and follow this trend. At present these traffic volumes exceed the highway design capacity during peak travel periods. If not improved the lack of capacity will ultimately lead to higher accident rates adverse economic impacts and increased travel times, thereby limiting the highways ability to function in a safe and efficient manner.

The Yakima River Bridge pier foundations are being undercut by the Yakima River and have resulted in the need to place riprap around the footings on a frequent basis to protect the bridge structure from catastrophic failure. The current bridge has inherent design deficiencies such as multiple shallow footings at various depths and does not meet current or projected capacity needs. If this problem is not addressed, the bridge may be subject to catastrophic failure. Failure of the bridge has the potential to cause fatality and the loss of a transportation corridor for the local community and its economy.

<u>Report Scope and Objectives</u>

The scope of this report is to evaluate the various identified alignments for this project in regard to their potential impacts to the Yakima River floodplain including floodplain functions, restoration potential, and review of the regulatory ramifications of the proposed action. This report will also evaluate the degree to which each alternative can accommodate implementation of the local jurisdictions' vision for floodplain management. The project limits for this report are where the project is contained within the 100-year floodplain. (***See Figure 1***).

The objectives of the report include:

- A description of the project and analyses of floodplain impacts for each alternative.
- Calculate potential floodplain function benefits based on Ecological Services/Acre /Year using models done by the National Marine Fisheries Service (NOAA 1995).
- Geospatial analysis of floodplain restoration potential for each alternative.
- Identification of the proportional mosaic scales of the floodplain as a baseline for quantifying habitat benefits for potential floodplain restoration.

Under normative conditions, floodplains, such as the Yakima River, function as a shifting habitat mosaic of wetlands, gravel deposits, riparian zones, and active channel networks (*Stanford et al 2002*). These functions are driven by, the cut-and-fill alluvial channel formation process. The ultimate goal of floodplain restoration is the identification of the proportional mosaic scales that can be extrapolated from historical photographs, or undeveloped reference sites. Once this is accomplished, performance curves that address the time steps required to re-establish floodplain functions (side channel formation, hyporheic interchange, riparian growth, etc) could be developed to track the progress of functional floodplain restoration.

Partnering and Opportunities

Floodplain evaluation and analysis provides opportunities to partner with local jurisdictions responsible for flood control activities. These jurisdictions are governed under local, state, and federal regulations regarding development and activities within the floodplain. Floodplain opportunities for this proposed project include:

- Reduction of property loss due to flood events.
- Strengthening and support of the local floodplain vision.
- Local level input on decisions that affect floodplains.
- Long-term reduction to existing and future public infrastructure expenditures and funding needs.
- Direct and indirect benefits to related environmental elements in the area.

Potential governmental partners identified for this project include:

- U.S. Bureau of Reclamation (BOR)
- U.S. Army Corps of Engineers (USACE)
- Yakima County - Flood Control District
- City of Yakima
- City of Union Gap
- Yakama Nation
- Washington Department of Ecology (WDOE)

SR24, I-82 to Keys Road
Yakima River Floodplain Consistancy Study Area

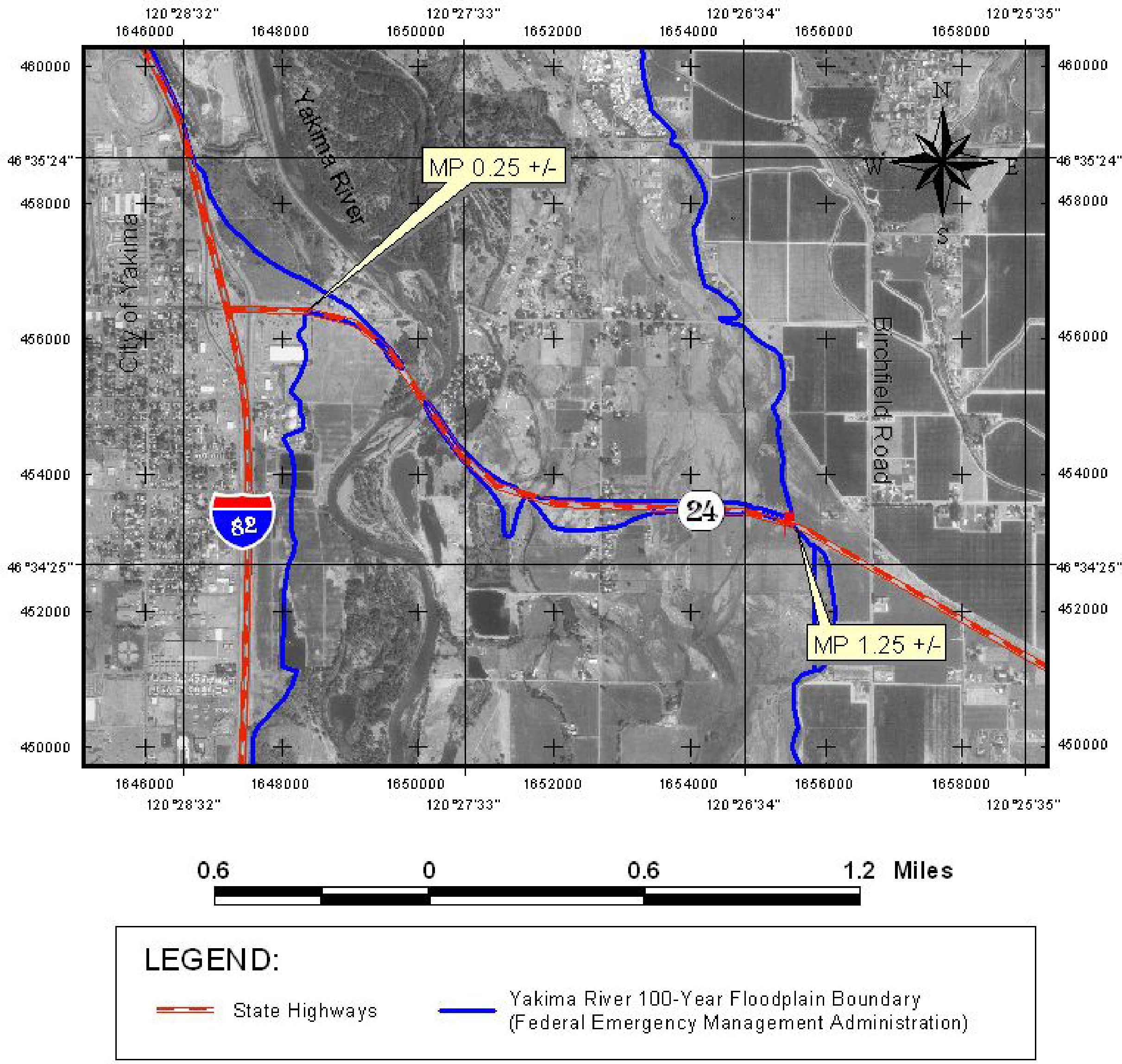


Figure 1: Floodplain Study Area Map

3.0 PROJECT ALTERNATIVES

This report focuses on the project alternatives as they relate to the Yakima River Floodplain. Refer to **Figure 1** to view each of the alternatives as they relate to the Yakima River 100-year floodplain.

2.1 Alternative 1 - No Build—Maintain Existing Bridge

<u>The SR 24 Roadway Would Remain on the Existing Alignment.</u>

- The scour condition on the Yakima River Bridge would continue to be a long-term maintenance issue.
- Travel from 18th Street in Yakima, to the Riverside Road intersection would continue to experience delays due to high traffic volumes.

<u>Alternative 1 Description within the Floodplain.</u> The existing bridge was constructed in 1957, and is located at RM111, approximately 1000- feet downstream of the former bridge site (Moxee Road). The existing span is approximately 600- feet in length crossing the river at a slight downstream angle. The bridge is supported on five sets of piers placed in the active channel of the river. The eastern abutment of the bridge is set into existing levees system that confine the river channel. The SR 24 road prism east of the crossing forms a secondary impoundment partition that bisects the floodplain behind and perpendicular to the existing levees. The western abutment lies in the velocity shadow of the Old Moxee Bridge with the western approaches acting as a levee, that protects the area to the south from over bank flooding. Thus, the SR 24 embankment can be effectively viewed as a functional part of the levee system because it forms a perpendicular partition to the floodplain

With regard to the existing span for SR 24, the channel affects the bridge much more than the bridge affects the channel. The current SR 24 Bridge over the Yakima River is experiencing critical recurrent scour problems. This has resulted in the need to place riprap on numerous occasions. Emergency rock deflector barbs and a rock wier between piers 2 & 3 have also been used in an attempt to rectify the problem. The cause of the scour however, is linked not only to the bridge piers but also, to the constriction of the channel within this reach by levees and their effect on river hydrodynamics. As such, attempts to deal with the problem have not been successful. To make matters worse channel migration to the west during and after the 1996 flood event along with ongoing recession of the west bank of the river in the project vicinity have exacerbated the situation even further. This movement of the active channel has brought the thalweg to bear on spread footings that were not designed to resist scour. Channel migration has changed the angle of attack allowing the thalweg to bear on multiple planes on the footing, as well as giving the river a much larger cross section that increases the scour potential. The angle at which the thalweg hits the footing forces the energy to flow perpendicularly to the plane of impact effectively increasing the cross section exposed to sour conditions which in turn increase scour impacts. This deflection of flow results in increased direction of force against the structure, increasing erosion not only on the riverward side of the footing, but behind it as well. While a replacement span constructed on drilled pilings would resist scour, the factors that make this reach unstable (channel constriction, break in slope, scour increased water velocities) will remain factors that increase risk to any structure in this location so long as the root causes of the instability (channel constrictions) remain characterized by a combination of local scour caused by the bridge piers and contraction scour caused by the general constriction of the channel by abutments; levees, etc. (*FHWA HEC 20, 1995*).

Alternative 2 – South (Low Profile) Alignment

- The SR 24 Highway would be expanded to four-lanes south of but adjacent to the existing alignment. Outside the existing Yakima River flood control levees new roadway fill materials will be required for the new eastbound lanes, while the existing roadway fill would be used for the westbound lanes.
- The existing Yakima River Bridge would be removed and replaced with a new four-lane bridge.
- The new Yakima River Bridge would be approximately 800- feet long and anchored into the existing location of the flood control levee structures.

Alternative 2 - Description within the Floodplain. The south low profile alignment; would be built utilizing the existing fill and by adding additional fill immediately south of and on the existing highway alignment. A new four-lane bridge would be built over the Yakima River immediately south of the existing bridge; and the old bridge and footings would be removed after the new bridge is constructed. The new bridge over the Yakima River; would be approximately 800- feet in length and would extend from the existing west flood control levee to the east flood control levee. The primary difference between Alternative 2 and Alternative 3 is the proposed length and vertical elevation of the Yakima River Bridge. Alternative 2 would be built using the existing flood control levees location for the bridge tie down points and would preclude the bridge from being an integral part any strategy for improve floodplain function through levee relocation in the future.

The location of the new bridge piers has not been determined at this time. However, pending final hydraulic and bridge design, bridge piers will be minimized within the Yakima River channel to the greatest amount possible and will be oriented so they will be parallel with the flow of the river. Approximately four (4) pier groups for the new bridge are needed to span the Yakima River. It is likely that each pier group will consist of five, four-foot diameter drilled shafts. Construction of the new bridge and demolition of the existing bridge may be able to be done from temporary work platforms or similar structures. The Contractor will construct and remove the bridges in accordance with forthcoming environmental permits.

Outside the location of the flood control levees, but within the 100-year floodplain, roadway fill materials will be added immediately south of the existing roadway to accommodate the new four lanes highway. The four-lanes would taper to; two-lanes after the intersection of Keys Road/SR24, but before the Riverside Road (South 33rd Street)/SR24 Intersection.

At Blue Slough the existing five-foot culvert that crosses under SR 24 may be either extended/replaced with a large culvert bottomless arch or bridged. Forthcoming analysis and design as well as compliance with the fish passage requirements will determine that appropriate Blue Slough conveyance structure.

Alternative 3 – South (Raised Profile) Alignment

- The SR-24 Highway would be expanded to four-lanes south of, but adjacent to, the existing alignment as in Alternative 2. Contingent on final flood levee locations and the associated timing of the levee relocation, existing and new highway fill required for the highway would either be scaled back to mirror the levee locations or removed after the levee relocation occurred. Outside the Yakima River flood levee locations, new roadway fill materials will be required for the new eastbound lanes while the existing roadway fill would be used for the westbound lanes.
- The existing Yakima River Bridge would be removed and replaced with a new four-lane bridge.
- The new Yakima River Bridge would be designed to allow a longer span bridge across the Yakima River to facilitate relocating the existing floodplain levees. This would require the new bridge design to be capable of accommodating a bridge between 1,200 and 2,200- feet long and 25' higher in elevation.

Alternative 3 - Description within the Floodplain. The south raised profile alignment is virtually the same as Alternative 2, the south low profile alignment, except for the bridge length and vertical elevation. As in Alternative 2, the new four-lane bridge would be built over the Yakima River immediately south of the existing bridge and the old bridge and footings would be removed after the new bridge is constructed. However, the new Yakima River Bridge for Alternative 3 may be between 1,200 and 2,200- feet in length and 25- feet higher in vertical elevation to facilitate improving floodplain and hydraulic function of the Yakima River at this location.

The location and quantity of the new bridge piers has not been determined at this time. However, pending final hydraulic and bridge design, bridge piers will be minimized within the Yakima River channel to the greatest amount possible and will be oriented so they will be parallel with the flow of the river. It is likely that each pier group will consist of five, four-foot diameter drilled shafts. Construction of the new bridge and demolition of the existing bridge may be able to be done from temporary work platforms or similar structures. The Contractor will construct and remove the bridges in accordance with forthcoming environmental permits.

Outside the location of the flood control levees but within the 100-year floodplain roadway fill materials will be added immediately south of the existing roadway to accommodate the new four lanes highway. The four-lanes would taper to two lanes after the intersection of Keyes Road/SR24, but before the Riverside Road (South 33rd Street)/SR24 intersection.

At Blue Slough the existing five-foot culvert that crosses under SR 24 may be either extended/replaced with a large culvert or bridged. Forthcoming analysis and final design will determine the appropriate conveyance structure for Blue Slough.

Alternative 4 – North Alignment

- The new SR 24 roadway alignment would be shifted to the north of the existing roadway and include a four-lane configuration. The new alignment would taper back into the existing SR 24 alignment near the Birchfield Road Intersection.
- A new four-lane bridge would be constructed on the north alignment and the existing Yakima River Bridge would be removed. The new Yakima River Bridge would be approximately 1,000- feet long depending on final design and environmental analysis of the project.
- The new alignment would require substantial new right of way and the abandonment and reclamation of the existing SR 24 alignment within the Yakima River floodway.

Alternative 4 - Description within the Floodplain. SR 24 would be realigned from the West Birchfield Road Intersection (MP 0.28) to approximately MP 1.91, which is 0.17 miles west of the Birchfield Road Intersection.

The North Alignment Yakima River Bridge crossing would be approximately 1000- feet long, four (4) to six (6) feet higher in vertical elevation, and would begin in the approximate location of the existing bridge embankment (Robertson Landing) and extend to the existing east bank levee. The final location and quantity of the new bridge piers has not been determined at this time but would be likely consist of four (4) pier groups. It is likely that each pier group would consist of five; four-foot diameter drilled shafts. Pending final hydraulic and bridge design bridge piers would be minimized within the Yakima River channel to the greatest amount possible and would be oriented so they would be parallel with the flow of the river. Construction of the new bridge and demolition of the existing bridge may be able to be done from temporary work platforms or similar structures. The Contractor would construct and remove the bridges in accordance with forthcoming environmental permits.

Outside the location of the flood control levees but within the 100-year floodplain, roadway fill materials would be added immediately south of the existing roadway to accommodate the new four lanes highway. The four-lanes would continue to Riverside Road, (South 33rd Street) and then taper to two-lanes before Birchfield Road.

After the Yakima River crossing the alignment then crosses Blue Slough at the same location where the new SR 24 alignment crosses Keyes Road. Large culverts or a bridge structure would be used to convey or span Blue Slough under the new alignment. Keyes Road would become a cul-de-sac on both the north and south side of the new SR 24.

Note: This alignment has since been eliminated from further consideration as a viable National Environmental Policy Act (NEPA) alternative.

4.0 PROJECT AREA DESCRIPTION

The project bisects the Yakima River at River Mile (RM) 111 after State Route (SR) 24 leaves the City of Yakima (*Sec 28, T 13N, R 19E, W.M.*) and proceeds to Moxee, the Hanford area and Othello . The Yakima River has a drainage basin of 15900-km^2 (6,139-mi^2) and flows 214- miles from the Cascade Mountains near Snoqualmie Pass to the Columbia River.

Previous resource characterizations have divided the basin into three ecoregions igneous rock formations and techtonic forces combined with distinct geological and biological components. These include the Cascades, Eastern Cascades slopes and foothills, and the Columbia basin *(Omernick 1987*). In the Cascade and Columbia basin ecoregions recent glacial activity and subsequent cut and fill alluvial processes to form the tributary and main channel networks. These processes deposited large amounts of lacustrine and fluvial material in the valleys forming deep porous bedrock sub basins. This geologic template resulted in a series of groundwater basins separated by natural knick points (Selah and Union Gaps) as well as, longer canyons (Yakima Canyon). This segmented geological setting influences the hydrologic cycle by establishing distinct hydrologic characteristics for each sub-basin (*Snyder and Stanford, 2001*).

The Yakima River passes through four large sub-basins; Roslyn, Kittitas, Upper Yakima, and Lower Yakima. The project area lies in the Upper Yakima Sub-basin within the Columbia basin ecoregion, which encompasses the Upper and Lower Yakima sub-basins. The Upper Yakima sub-basin is geomorphically divided into three reaches; the Upper reach—Yakima Canyon to Selah Gap, the Middle Reach, from Selah Gap to the existing SR 24 Bridge, and the Lower Reach- from the SR 24 Bridge to Union Gap. *(Ueblacker 2002*) The Middle and Lower reaches encompass the project area. The existing bridge site marks the reach boundary. Both reaches are described below.

<u>Yakima River Middle Reach</u>

The Middle reach begins below Selah Gap, where the Yakima River is joined by its largest tributary, the Naches River, and is confined by a federal levee system constructed following the 1933 flood. The middle reach includes the Yakima River floodplain south of the Naches River downstream to SR 24. Both the Yakima and Naches River floodplains are constricted by the federal levee system, which has cut off many overflow channels that historically conveyed or stored floodwaters, and greatly simplified river channel geomorphology. (***See figures 2-6 historical floodplain alterations***)

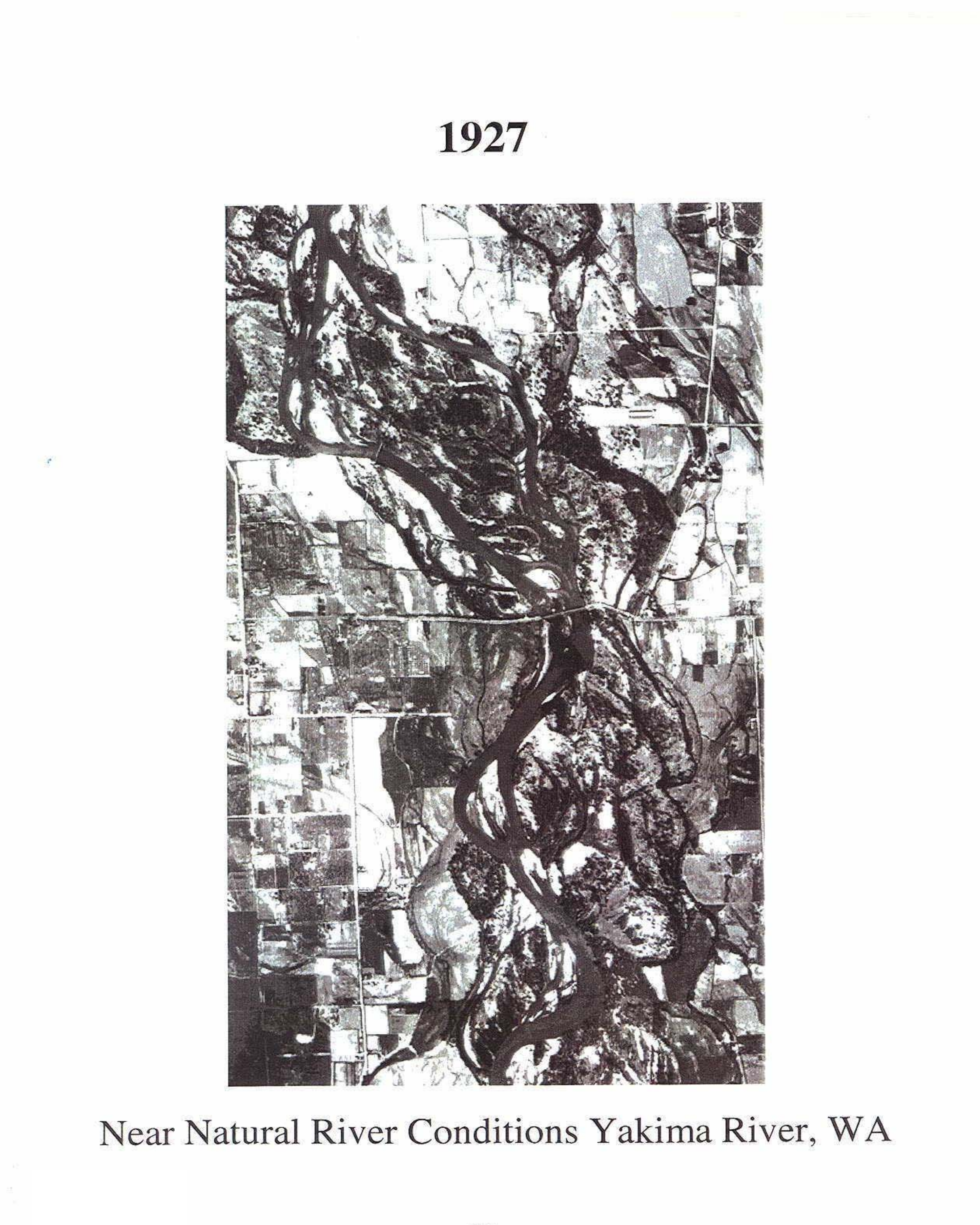
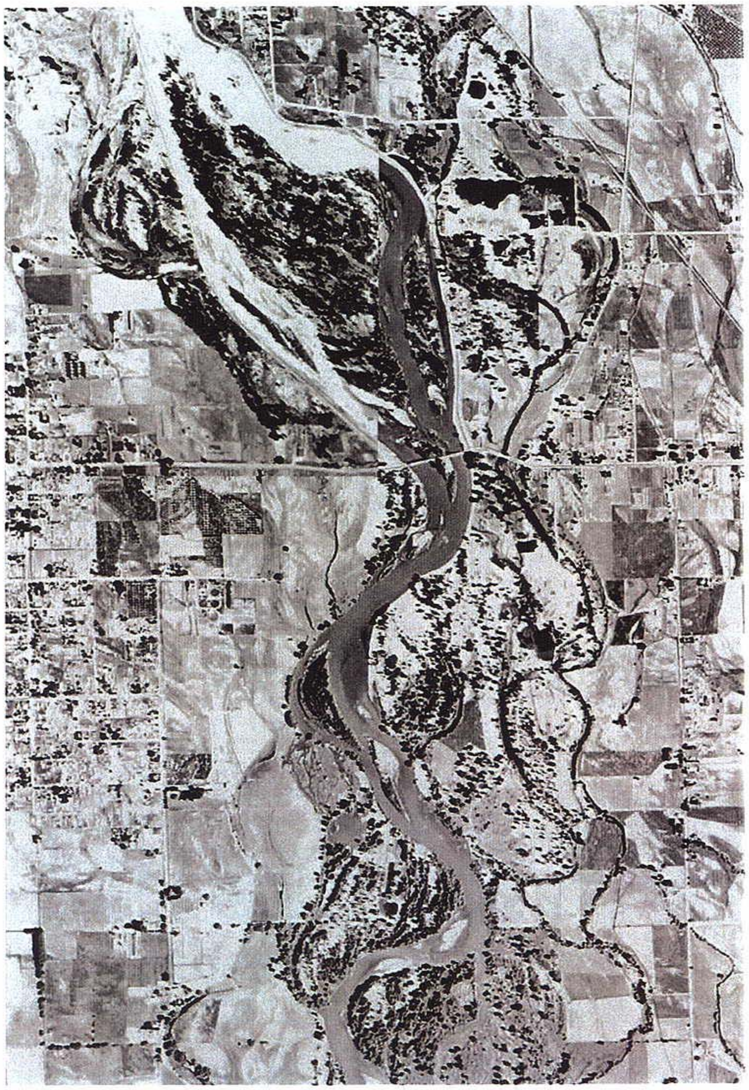


Figure 2: 1927 Aerial Photo of Project Area

1949



Revetments

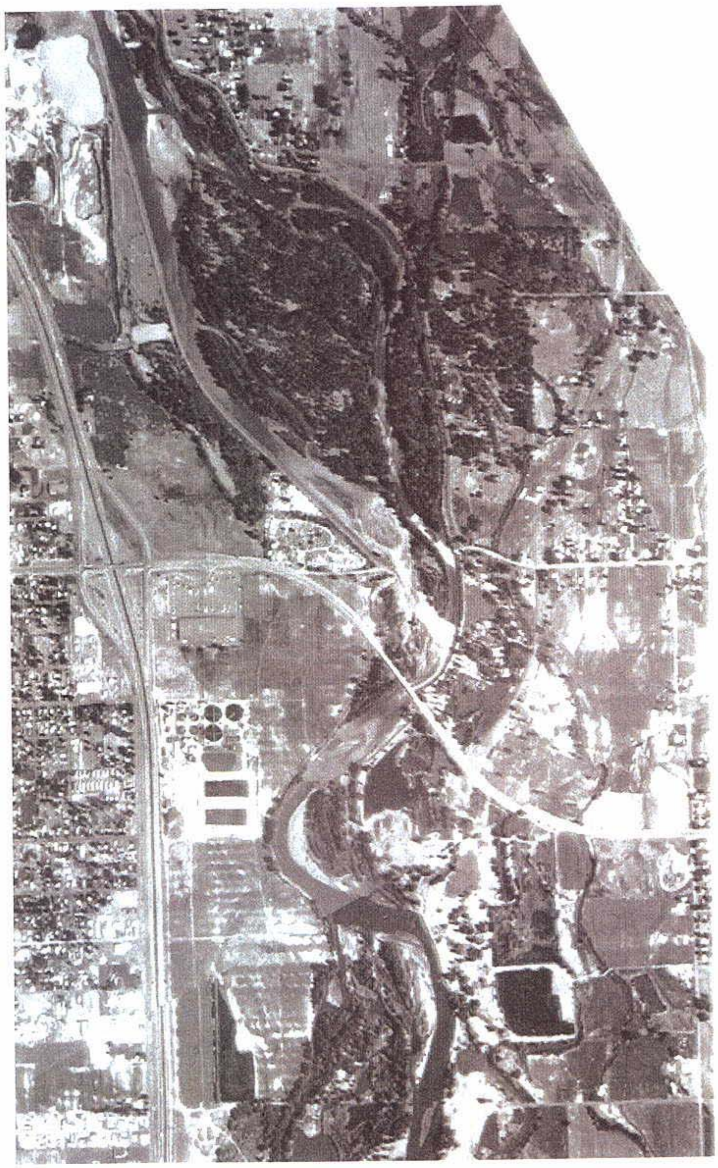
Figure 3: 1949 Aerial Photo of Project Area

1966

Gravel Mining & Highway Construction

Figure 4 : 966 Aerial Photo of Project Area

1979



More Flood Plain Encroachment

Figure 5: 1979 Aerial Photo of Project Area

1999

Figure 6: 1999 Aerial Photo of Project Area

The 5.6 mile long reach has a slight meandering pattern. It is 15.4- foot-per-mile gradient is steeper than the adjacent reaches, and the floodplain is considerably narrower averaging 1,980 feet in width. Near the middle of the reach, the skew of the piers and angle of flow approach to the Terrace Heights Bridge (RM 114.5) results in a structure, which is, very inefficient in flow conveyance during flood flows. This exacerbates backwater and deposition of bedload upstream of the bridge. Concentrated flow direction and reduced bedload downstream of the bridge have resulted in a narrowing of the active channel and scour of the bed and adjacent levees. In this way dis-equilibrium in bedload transport reinforced. In the downstream portion of the reach constriction of the channel by levees has resulted in bed aggradations that have perched the active floodplain within the levees and above the surrounding floodplain. As mentioned above, the Yakima River in this reach is completely controlled by levees. Thus, all of the expression of sediment transport, erosion, and deposition are contained within the levees except in the event of a levee breach or overtopping event. This exacerbates the effect by concentrating it in a narrow cross section of the floodplain where the prevalent constricted condition of the floodway is increased by bridge abutments and piers, sharp meander bends, and other features. Because the average depth of the water in reaches bounded by levees in areas of lower velocity the tendency for sediment to settle out of the water column is enhanced resulting in bed and floodplain aggradations above the point of increased constriction. In some places this difference can be eight feet or more (*Freudenthal Pers Comm., Park field observations 2002)*. In addition, as the floodplain aggrades, the river channel itself becomes narrower and deeper increasing the hydraulic efficiency of the channel and its ability to erode. As the perched floodway aggrades higher and higher above the surrounding floodplain and the channel continues to narrow, erosive energy, exerted against the levees increases and increases avulsion risk with associated public safety concerns. Conversely, as the floodplain aggrades the overall flood conveyance capacity of the leveed portions of the river continually decreases resulting in either risk of overtopping the levee system, or ongoing operations to raise the elevations of the levees to maintain conveyance capacities. If the current trends in aggradation continue, the levee system will continue to be in increasing danger from both erosion due to increased energy, and overtopping due to aggradation. As mentioned above, under normative conditions floodplains, such as the Yakima River, function as a shifting habitat mosaic of wetlands, gravel deposits, riparian zones, and active channel networks. These functions are driven by cut-and-fill alluvial channel formation processes. These processes maintain floodplain functions such as storage channel and side channel complexity/connectivity, hyporheic exchange. Development has constricted the floodplain, which has degraded floodplain biotic function, and forces the expression of cut and fill processes within a highly truncated cross section. The current configuration combined with the backwater effects from the existing SR 24 span exacerbate the constriction- driven dis-equilibrium of the channel bed in the middle reach with negative implications for both flood safety, and habitat viability by perturbing normative floodplain functions.
**Note – This area needs to be further researched.*

<u>Yakima River Lower Reach</u>

The lower reach extends from the current SR 24 Bridge location to Union Gap. As the river passes SR 24 the floodplain widens to an average of 5,125- feet.

A stream power analysis done in 2002, reveals that the reach is steeply sloped at the top of the reach and is somewhat incised with a gradient of approximately 31-feet per mile for the first 1500- feet of channel immediately south of the bridge (*Lorang, 2002*). This is also indicated by the extensive scour history at the SR 24 Bridge. Further downstream, the gradient flattens to 11.1- feet per mile. Like the middle reach, the downstream portion of the lower reach is aggrading between the levees. The risk of avulsion in this reach is much higher than that in the middle reach. The reason for this is that the confining levees that extend downstream from SR 24 provide much lower levels of flood protection than those located upstream of the bridge. A right bank levee extends approximately one-mile downstream of the bridge. This levee protects the City of Yakima Sewage Treatment Plant.

A left bank levee extends for approximately two-miles downstream. This levee protects several gravel pits among other properties. Private levees have also been installed in this reach, which is 4.6-miles long. These levees are not part of the Federal Levee System and are not of sufficient height to withstand larger flood events. The levees in this reach are also inadequate in terms of construction. These levees (or "sugar dikes", as they are called by flood fighters because in floods they tend to dissolve as if made of sugar) are made chiefly of river transport gravels, sand, cobbles and cannot withstand major flood flows. Because of their inadequate height and construction levees in this reach have been reinforced under emergency conditions on numerous occasions. Despite these efforts however the objective risk of levee failure in this reach continues to increase as the channel aggrades (*Yakima Comprehensive Flood Hazard Management Plan [CFHMP] 1998; Freudenthal, Pers Comm).*

<u>Project Area Levees</u>

Like much of the Yakima River system, the reaches encompassing the project area are controlled with levees that constrict the channel. These levees were built at various times and are under the jurisdiction of varied authorities. The levees north of the existing SR 24 alignment on both sides of the River are part of a federal level project, built in 1948 as a response to the 1933 flood. These levees have been upgraded at least twice in most locations to provide the specified level of protection for a 100-year flood. The right bank levee (looking downstream) (*designated FEDRB4 in the Yakima County Flood Control Works Inventory, see Appendix A*) protects an auto wrecking yard. The Left bank levee (YSEG7A) protects mixed-use area including a KOA campground, residences, businesses, and agricultural land.

Issues surrounding flood safety and risk of levee failure or overtopping become critical as the river moves downstream through the project area. The current SR 24 alignment forms a demarcation between federal levees, engineered and constructed to withstand 100-year floods and non-federal levees that are not. The location of high avulsion potential and stream power, and the proximity of large gravel pits to anticipated avulsion flow pathways all heighten flood safety concerns in the lower reach of the project area. Examinations of the Yakima floodplain have thus far focused either on flood level reduction (hydro modification and levees) or on habitat impacts and potential restoration. Clearly, a more comprehensive evaluation of the river conditions and processes appropriate for consideration in both design of the bridge and the floodplain vision is required to address both areas of concern. It is the perturbation of natural riverine processes that lie at the root of both habitat degradation and increased flood damage costs and risk. The fundamental issue here is to strive for a natural balance that serves the needs of both flood hazard reduction and habitat restoration by mimicking naturalized riverine processes and floodplain functions. At the heart of this is the provision of storage that provides functional habitat, while giving the river a larger cross section within which to express erosive and depositional forces and re-establish cut- and- fill driven habitat mosaic of normative floodplains while taking erosive pressure off of existing and proposed infrastructure.

The levees, on the east bank, south of the existing alignment and bridge provide only limited flood protection. They provide only a five year level of flood protection (*Yakima Co. CFHMP 1998*). Emergency work done to the levee has increased this to a 25-year (35,000cfs) level of protection (without freeboard), however this is not reflected in the county's levee inventory. Even at a twenty-five year level of protection with no freeboard, at flows higher that 35,000cfs, overtopping of the levee would begin approximately 200 feet downstream of the current SR 24 Bridge. This levee protects a series of gravel pits. The risk of river avulsion into these pits is a great concern here. While this levee received emergency reinforcement during the 1996 flood, it would still require between 1.5 to 6- feet of additional height to provide the specified 100-year protection with three feet of freeboard. (*Yakima CFHMP 1998*).

The levee fronting the right bank downstream of the existing bridge (YSEG8) is managed by the City of Yakima. The Yakima Comprehensive Flood Hazard Management plan lists this levee as providing only five-year protection with one foot of freeboard. It is constructed of riprap, and varies between zero and five feet in height, and is 5477- feet in length *(*See levee inventory sheets Appendix A*)*. It was built to protect the sewage treatment plant for the City of Yakima. This levee failed to meet Pl-99 levee criteria.

Inventory sheets for the levees in the project area are contained in *Appendix A*.

<u>Yakima River Reach Summary</u>

Floodplain conditions in both reaches of the project area suffer from severely degraded floodplain functions stemming from severe floodway constriction, and floodplain disconnection. The upstream portions of both reaches contain large areas of channel scour, while the lower portions of each reach are aggrading above the floodplain increasing flood hazard and avulsion risk. The dis-equilibrium of sediment transport processes as expressed in the pattern of alternating channel scour and aggradations is occurring because the entire force of the river is concentrated between the levees *(Park Pers Obs, Boulton 2001)*. In this way, the levees, while built to improve flood safety, are themselves partially driving flood risks, particularly in the lower reach of the project area (*Park, Pers obs, 2002*). It is for this very reason that local government is looking at restoration options as a way to provide additional flood water storage, while alleviating channel constrictions to help attenuate the imbalance of sediment transport by allowing natural cut-and fill-alluvial processes to redistribute sediments over a broader cross section of the original floodplain (*Freudenthal, Pers Comm*).

The levee data indicated that flood risk due to overtopping and or channel avulsion due to levee failure increases south of the existing alignment (see Appendix A). While the levees north of the existing route are part of the federal levee system, and have recently been upgraded to meet PL-99 specifications, for the 100 year flood event those south of the existing alignment, are not managed as part of the federal levee system, are in different jurisdictional hands, and do not have the height, construction, or certification to provide anywhere near the same level of protection.

The increased risk in the lower reach is exacerbated by the types of facilities found there. The City of Yakima Sewage Treatment Plant is located behind the right downstream levee. In the event of failure of the levee YSEG8, ponds serving the plant would likely be inundated with resultant loss of sewage treatment capacity for the entire City of Yakima, City of Union Gap, and portions of Yakima County. Water contamination problems would also likely ensue as a result of combined sewer overflows and possible backwater effects to the interceptor system.

In conclusion, the reaches encompassing the project area have been systematically constricted and simplified due to various development activities over the past century. This has exacerbated problems with sediment transport balance, and other floodplain functions, resulting in increased environmental degradation, infrastructure damage (bridge scour and levee erosion), and flood damage risk to residences and commercial/public structures located within or adjacent to the floodplain.

<u>Hydrogeology</u>

The Upper Yakima sub-basin is typical of the Columbia Plateau geology consisting of numerous lava flows of tertiary age Columbia River Basalt overlaying preexisting formations. The Upper Yakima Basin was deformed into a series of southeast trending anticlinal ridges and synclinal valleys. The Yakima River cut through these ridges dividing the region into distinct basins at the Yakima Canyon, Selah Gap and Union Gap *(Kinnison and Sceva 1963)*.

Within the Columbia basin ecoregion of the Yakima River, the Columbia River basalts function as a locally important aquifer system formed of interbeds and overlying sediments. These alluvial aquifers are noted for heterogeneous and anisotropic properties due to their location within the fluvial environment of the Yakima River *(Ueblacker, Arango, Eitmiller,2001).*

Under normative conditions, extensive hydrologic exchange between the surface, hyporheic, and groundwater zones would have occurred in the vast alluvial valleys and floodplains of the reach containing the project area which would have functioned as hydrologic buffers distributing the energy of peak flows and providing important distribution, temperature moderation, and nutrient exchange functions *(Stanford, Snyder, etal 2002).*

The geology of the immediate project vicinity confirms that the reach performed critical hyporheic functions. Borings taken in 1956 preparatory to construction of the existing SR 24 span over the Yakima indicated that coarse alluvial deposits of sand, gravel, and cobbles extended to at least 42-feet in depth. The corridor analysis report presenting those findings concluded that these deposits could easily approach 100-feet in depth in the center of the floodplain valley. (*Tams Consultants, 1993)*

On a large spatial scale each of the Yakima sub-basins is viewed as down welling, or losing surface water to the hyporheic and groundwater systems (i.e. a near-surface aquifer) in the upstream portions of the valley and upwelling or gaining surface water from groundwater and hyporheic systems in the lower portion of the valley. This upwelling is driven by decreasing size of the sedimentary aquifers causing groundwater to move back into the river. During spring and summer runoff down welling into the surficial aquifer raises the overall water table in the valley. As flows drop off in fall this stored, cool, well oxygenated water, is discharged from the groundwater system back into the stream. This exchange between surface and ground water is extensive and performs important functions in maintaining temperature, oxygen levels, exchanging nutrients, and supporting biotic functions for both macroinvertabrates and fish *(Snyder and Stanford 2001)*. The project reach is located in the middle of the valley, where the river transitions from a down welling to upwelling area of the sub basin. (ibid). Thus, channel constriction in the reach has seriously degraded hyporheic function throughout the reach by lowering the elevation of the surficial aquifer reducing the ecological service of hyporheic function (down welling/upwelling exchange between surface and ground water). The effects of floodplain dis-connectivity and channel constriction on surface/groundwater interaction and other floodplain functions is described schematically below in **figure 7**

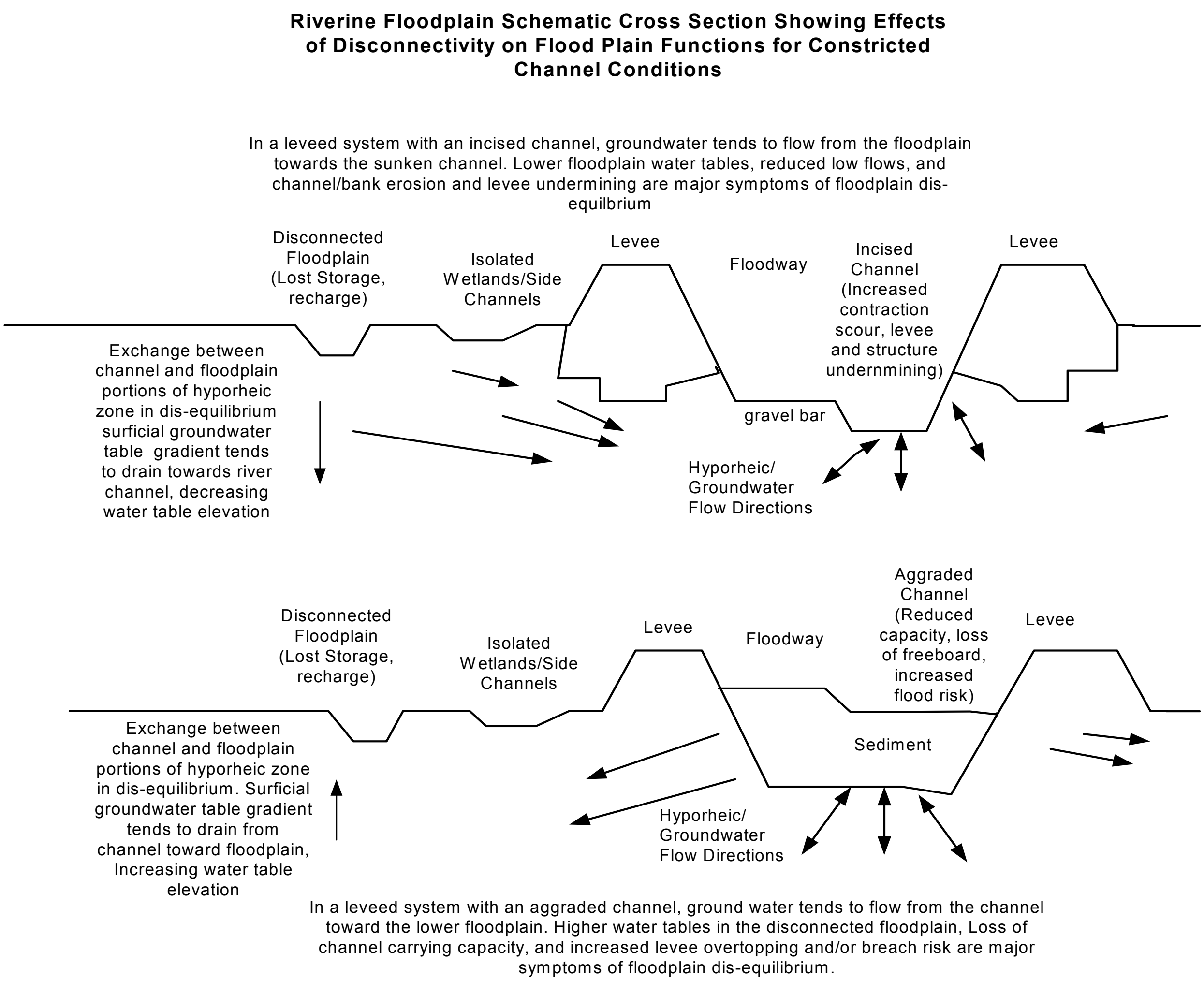


Figure 7: Floodplain Dis-connectivity (Park 03)

Because of hydro-modifications for irrigation and power production this the Yakima experiences periods of both dewatering and elevated flows relative to the historic flow regime *(Snyder and Stanford 2000).* In addition there is a downward trend in annual mean discharge for the Yakima at Union Gap, dropping from 134 m^3/s to 108m^3/s between 1926 and 1977. *(ibid after Vacaro, 1986a*). This net decrease in flow is largely due to extensive irrigation diversions upstream of the reach, but is also influenced by degraded floodplain functions stemming from floodplain dis-connectivity see above diagram. Whatever the cause(s) the implication is that there will likely be less water available for irrigation, for moving sediment, or for supporting biological functions. A comprehensive study of surface/groundwater relationships in the basin would be necessary to answer the questions that reduced discharge and perched channel conditions raise with regard to each other, as well as to hyporheic function and sediment transport. For the purposes of this effort however, the description presented is sufficient to describe the degraded conditions of floodplain function within the project reaches.

Levee and Flood History

The original Holocene floodplain for the Yakima River between Selah gap, and Union gap encompassed 2325 hectares (5745 acres*)(Ueblacker, 2002*). Because of the availability of fertile soils, water, forage, and wood for fuel and building, settlers and ranchers began to exploit the rich alluvial floodplain and channel networks around 1860 (*Lyman, 1919*) by building and operating extensive irrigation diversion systems along the Yakima and Naches Rivers at numerous locations.

By 1915, the connected portion of the Holocene floodplain in the Union Gap reach had been reduced to 1840 hectares (4546 acres) currently the surficially connected Holocene floodplain within the Union Gap reach totals only 40 % of the original total 920 hectares (2273 acres). By 1933 large reservoirs, main-stem river diversions, and water delivery systems had altered the flood pulse of the Naches and Yakima Rivers. Ranching, farming, land clearing, woodcutting, and transportation corridors continued to impinge on floodplain processes *(Ubelacker et al, 2000).*

The diking and flooding history of the Yakima reads like a chain reaction of floods, levee building in response to floods, followed by flooding problems in a new location as levees and other structures shifted flood storage and impacts elsewhere, precipitating damaging floods in new locations, and necessitating additional flood control levees.

Secondary Levee Function: Levee Failure Risk

The existing bridge location marks the delineation line between the federal levee system north of the alignment, which provides certified 100-year protection, and the levees south of the alignment, which provide only marginal protection. Channel changes have resulted in the loss of freeboard that has resulted in the need to elevate and re-certify most of the levees within the project area on more than one occasion, indicating that increased flood risk due to the perturbation of channel characteristics and bedload transport dynamics is a chronic problem in the reaches encompassing the project area (*FEMA 1998*). In the event of failure of downstream levees, the SR 24 Road would serve as a floodplain partioning levee. Ostensibly, this would protect the KOA campground, propane distributor, as well as other businesses and residences north of the route from backwater flooding effects. The problem here is that the road is not designed to function as a levee. The route has neither the heights nor construction to qualify for certification as a PL-99 levee. Risks associated with backwater flooding effects will be discussed further in the gravel pit section of the reports. In addition a flood model simulating removal of the existing levees and establishment of setback levees must be done in order to calculate new Base-Flood-Elevations and freeboard requirements for the road. Blue Slough limits the ability to provide backwater protection to properties north of SR 24 and below the base flood elevation.

Flood Frequency

Flooding is common on the Yakima. The river has exceeded flood stage 45 times, since 1894. Yakima has been declared a federal disaster area due to flooding nine times, since 1970,most recently in 1995 and 1996. The 100-year flood flow totaled 56,000cfs *(measured at the USGS gauge at Parker Dam, RM 103.8 in February, 1996*). The Yakima has an annual normal high flow of 14,590cfs (*WSDOT 2002*). Flood frequency curves for two periods (1909-1990, and 1933-1990) are presented below to show the range of volumes for flood frequencies experienced in the project area. (***See Figure.8***)

Note: That the hydrograph for the later period encompasses the years, since major levee building has taken place. While magnitude for large events has decreased flood magnitude at smaller (10-yr) events has increased slightly.

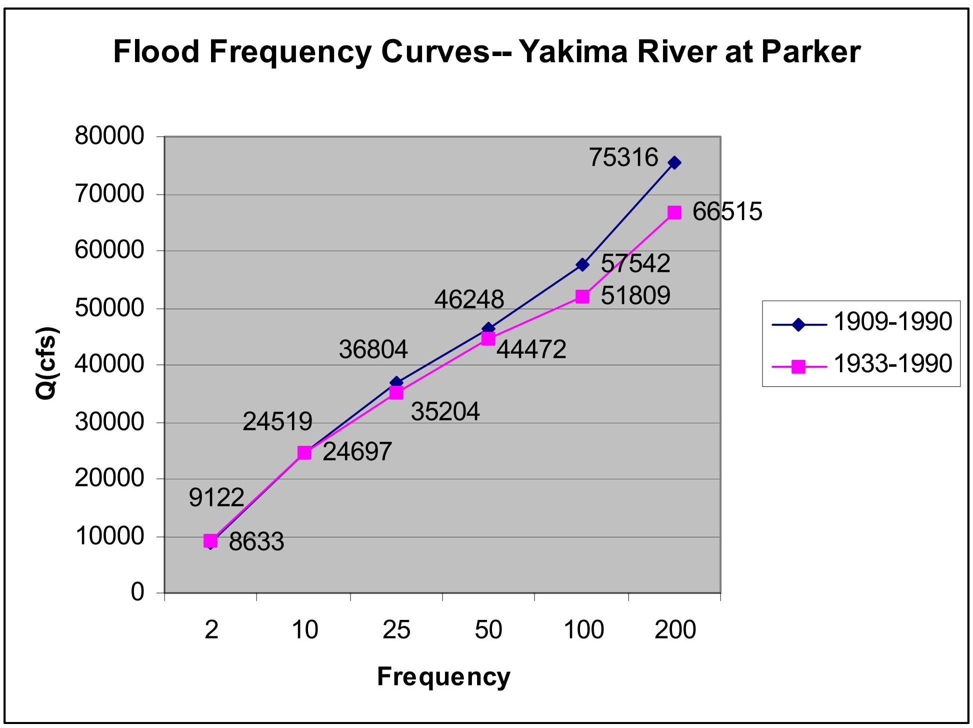


Figure 8: Yakima River Flood Frequency

(Source: Yakima CFHMP)

Channel Migration

As described above, cut-and-fill channel migration processes are essential driving functions in systems such as the Yakima. The Yakima River's steep gradient and easily eroded alluvial substrate promote channel migration across the floodplain, forming a shifting mosaic of floodplain habitat types: (channel networks, gravel bars, wetlands, riparian zones).

Historical aerial photos show a number of abandoned channels. ***(See Figure 9***) Lateral migration has been estimated to occur at an average rate of 30 feet per year, ranging up to 75 feet per year, depending upon frequency and magnitude of flood events (*Dunne,* 19*76 also CFHMP 98*). Analysis of channel migration completed for the CFHMP show the greatest lateral activity occurs just downstream of the SR 24 Bridge. (ibid)

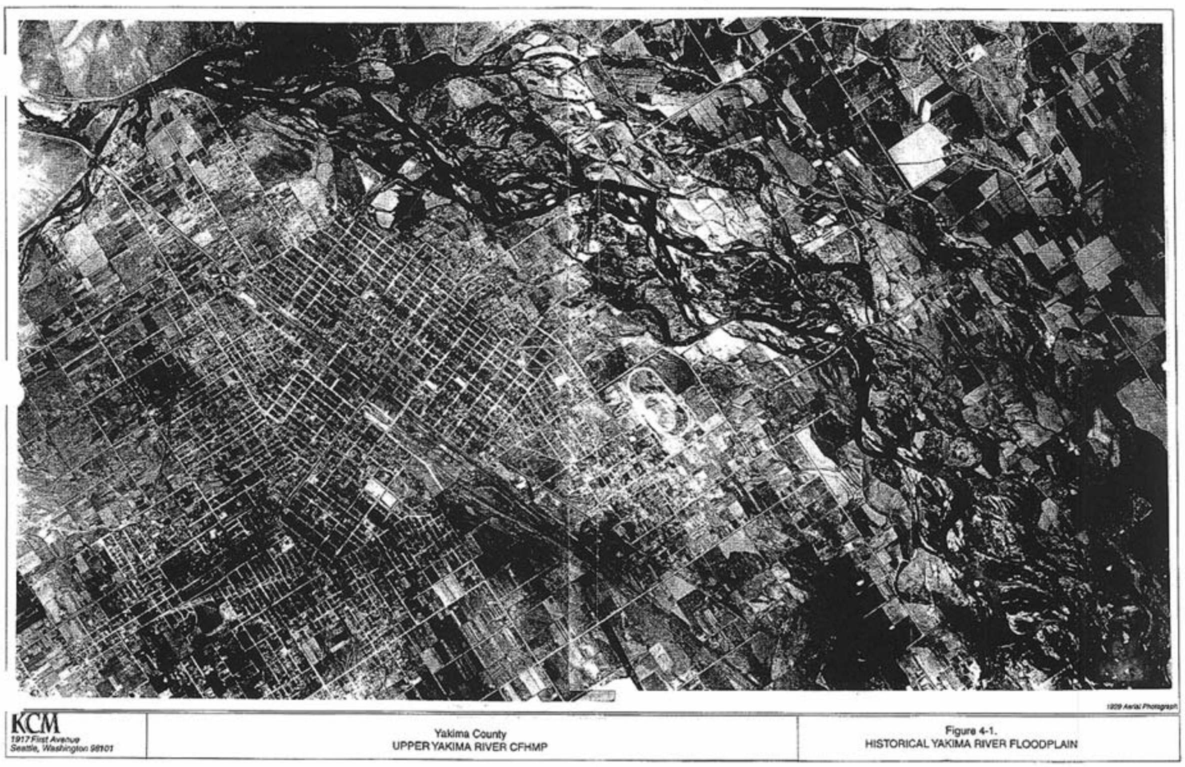


Figure 9: Historical Floodplain Channels

Channel avulsions have also taken place in the Yakima River floodplain. The potential for avulsion within the project area has been greatly exacerbated by levee constriction, and gravel mining. Several deep pits are situated just downstream of the existing SR 24 Alignment, separated from the active channel only by gravel levees that are not designed to withstand major flooding events. If the levee protecting these pits were to fail during a large flood event, then considerable portions of the flow and bedload could be directed into the pits. This poses not only a risk to the pits themselves, but to the river channel (both adjacent to the pits and for a considerable distance downstream) and adjacent infrastructure as negative hydrogeologic effects in the form of head-cutting, downstream erosion, and entrainment of bedload may result.

Sediment Transport and Deposition--Avulsion Risk

The Yakima bedload at the Parker station is estimated at 57,000 tons per year (*Dunne 1976*). While this is not excessive for a river of the Yakima's size, a floodplain modification have thrown sediment transport dynamics out of balance and has exacerbated problems associated with dis-equilibrium in sediment transport. Most notably this is expressed as bed aggradations, perched floodplains and localized (bridge, roadway, levee, etc) scour. The sediment deposited in the river channel promotes more rapid erosion channel migration, and can reduce the capacity of the floodplain and river channel to store and convey floodwater. When bed aggradations between the levees become pronounced then flooding and avulsion risks increase.

Avulsion risk can be derived from the differentials found between several interrelated factors: the level of bed aggradation in the active floodway versus the level of the surrounding floodplain the elevation of the water surface at peak flow versus the elevation of the levee, and the erosive stream power of the peak flow versus the stability of the levee structure (which is dependent upon its composition and method of construction). As mentioned above in the reach description portions of the floodway in the reaches encompassing the project area are aggraded above the surrounding floodplain. One of the difficulties in assessing avulsion risk for the Yakima is that most of the cross sections prepared for the river end their transects at the top of the levees. As such, no comparative elevations of the surrounding floodplain are examined. For these analysis three cross sections including data points outside of the levees were prepared by WSDOT ***(See Figure 10 transect locations).***

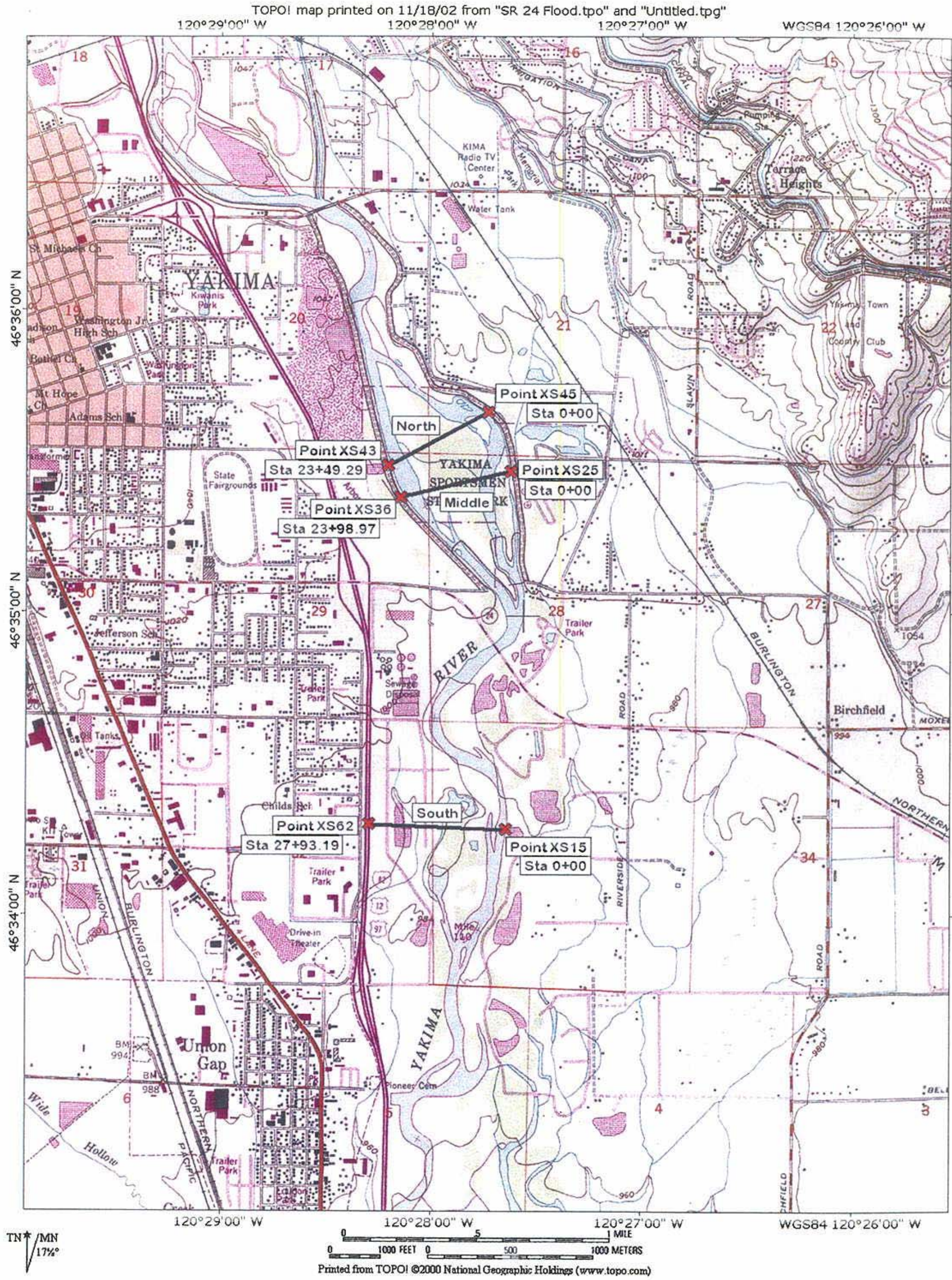


Figure 10: Yakima River Cross-Section Location Map

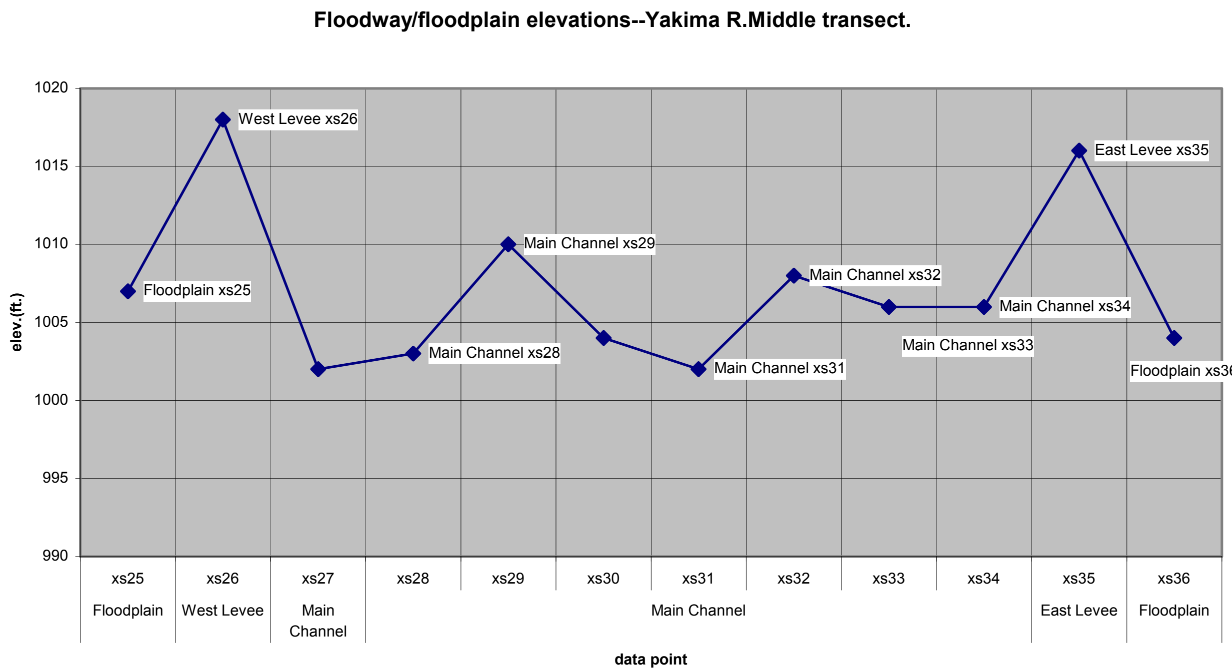


Figure 11: **Middle Transect Cross-Section, Yakima River**

Figure11 shows Floodway/floodplain elevation plots for the middle transect. This transect clearly indicates that most of the floodway is higher in elevation than the floodplain east of the river as exemplified by point XS 36. The high point in the floodway (XS 29) is six-feet higher than the elevation of the floodplain outside of the levee. It is important to note here that these measurements are taken under low flow conditions. Adding a base flood elevation of ten or twelve feet (not unheard of at this location) to simulate peak flows starts to bring the avulsion risk into focus

The presence of numerous gravel pits on the floodplain of the project area makes for an increased avulsion risk, while making characterization of that risk much more difficult. Extensive gravel extraction from the three largest pits south of the existing bridge encompasses approximately nine acres that poses a significant entrainment risk in the event of river avulsion. The deepest of these is some twenty-five to thirty-one feet below the grade of the floodplain. (*Wayne Kalbfleisch RPMCo pers comm.).* As the pits have been operated by various entities at various times, estimates of the total gravel extracted from the vicinity vary greatly.

The risk of avulsion is related to the amount of work (sediment transport, and erosion of the bed or banks) the river is capable of doing *(Lorang, 2002)*. This can be approximated as stream power as described by the equation

$$P = \rho g h S V$$

Where **P**=stream power in Watts/meter of stream width, ρ is the density of water, **g** is the gravitational constant, **h** is water depth, **S** is slope, and **V** is flow velocity.

Slope is a key driver in avulsion risk, since slope is a primary factor in the equation. In addition, velocity is determined partially by slope, making it both a primary and a secondary factor in driving stream power. Therefore slope is an exponential driver in stream power.

Expressed in simplest terms velocity (**V**) increases as the square root of depth and the square root of slope as affected by the smoothness of channel boundaries.

$$\mu = C\sqrt{RS}$$

Where μ is velocity, **C** is an inverse resistance factor for boundary conditions **R** is the hydraulic radius (approximately equal to the mean depth for wide channels), and **S** is the energy gradient as approximated by the slope of the water surface *(Dunne and Leopold, 1978).*

The difference in elevation between the water surface inside the aggraded floodway and the flood elevation of the floodplain or gravel pit outside of the levee is a key determinant for estimating avulsion risk, which can thus be summarized as the sum of two immediate and adjacent features; aggradation between levees and gravel pits outside of non-standard levees. Because slope drives both stream power and velocity, increasing differences between water surface elevation and floodplain or gravel pit floor elevations can have an exponential effect on hydraulic forces and thus avulsion risk in the event of a river avulsion into lower elevation areas such as pit sites.

With regard to the project area immediately south of the current SR 24 alignment, slope potential, stream power, channel conditions, and levee height and composition come together to form a particularly bad combination with regard to avulsion risk.

The levee height on both sides of the river drops from 100 year recurrence interval protection to between 5 and 25-year recurrence protection. This is three to six feet lower than the 100 year levees located upstream of the current span. To make matters worse, the downstream levees are constructed chiefly of river transport-sized material, riprap, cobbles, sand and gravels, that are not very resistant to erosive force, and readily moved in high water events *(Dunne et al, 1976 also see appendix A levee inventory sheets, CFHMP).*

This unfortunately coincides with the location of the deepest gravel pit in the project area with a channel floor some thirty-one feet below grade, and in an area of already high avulsive potential as described in the recent stream power analysis performed on the reach *(Lorang,2002*). The channel is highly constricted, adding to the slope of the water surface above the bridge. Below the current span, the simplified channel provides little resistance in the way of channel complexity further increasing velocity and stream power.

This combination of higher stream power, less robust levees and the presence of a deep gravel pit adjacent to the river, increases each of the factors driving avulsion risk.

The risk of avulsion in the project area is a serious, yet not well-studied threat. Full quantification of the risks lies well beyond the scope of this study, and the responsibility of the WSDOT. However, WSDOT infrastructure is at risk, as is many other public and private structures located adjacent to a floodway.

This report recommends that future floodplain restoration efforts must begin with an in-depth study of avulsion risks, starting with the gathering of LiDAR (Light Detecting and Ranging) data to provide two foot topographic contours, and updated cross sections that tie in elevation plots both inside and outside the levee constricted floodway. This will give more evidence to the predicted relationship of an upgraded floodway with deposition above adjacent floodplain land. Lastly, avulsion risk in large areas of bed aggradation needs to be addressed in the early stages of floodplain restoration planning. This means that floodplain restoration activities need to be methodical and strategic to avoid increasing short-term flood risks.

Project Considerations

When looking at bridge location, consideration of two interrelated geomorphic factors are crucial: channel stability, and stream power. The Yakima River CFHMP presents data categorizing areas of rapid channel migration ***(See figure 12*** *Yakima CFHMP after Dunne, 1976)*. Location of bridge alignments in relation to these zones can be used as a tool for assessing relative risk of channel migration to the proposed structure. The west abutment of the current span lies within the unstable channel zone. Replacement abutments, should avoid this zone, regardless of alignment chosen, or the type of structure proposed. The bank here is receding, and all indications are that it will continue to recede. In addition, Yakima County is considering modifications to the west bank levee immediately upstream to reduce channel constriction. Modifying this levee would likely reinforce this trend, and as such should be evaluated as a potentially foreseeable future condition. Continued coordination with Yakima County is therefore highly recommended.

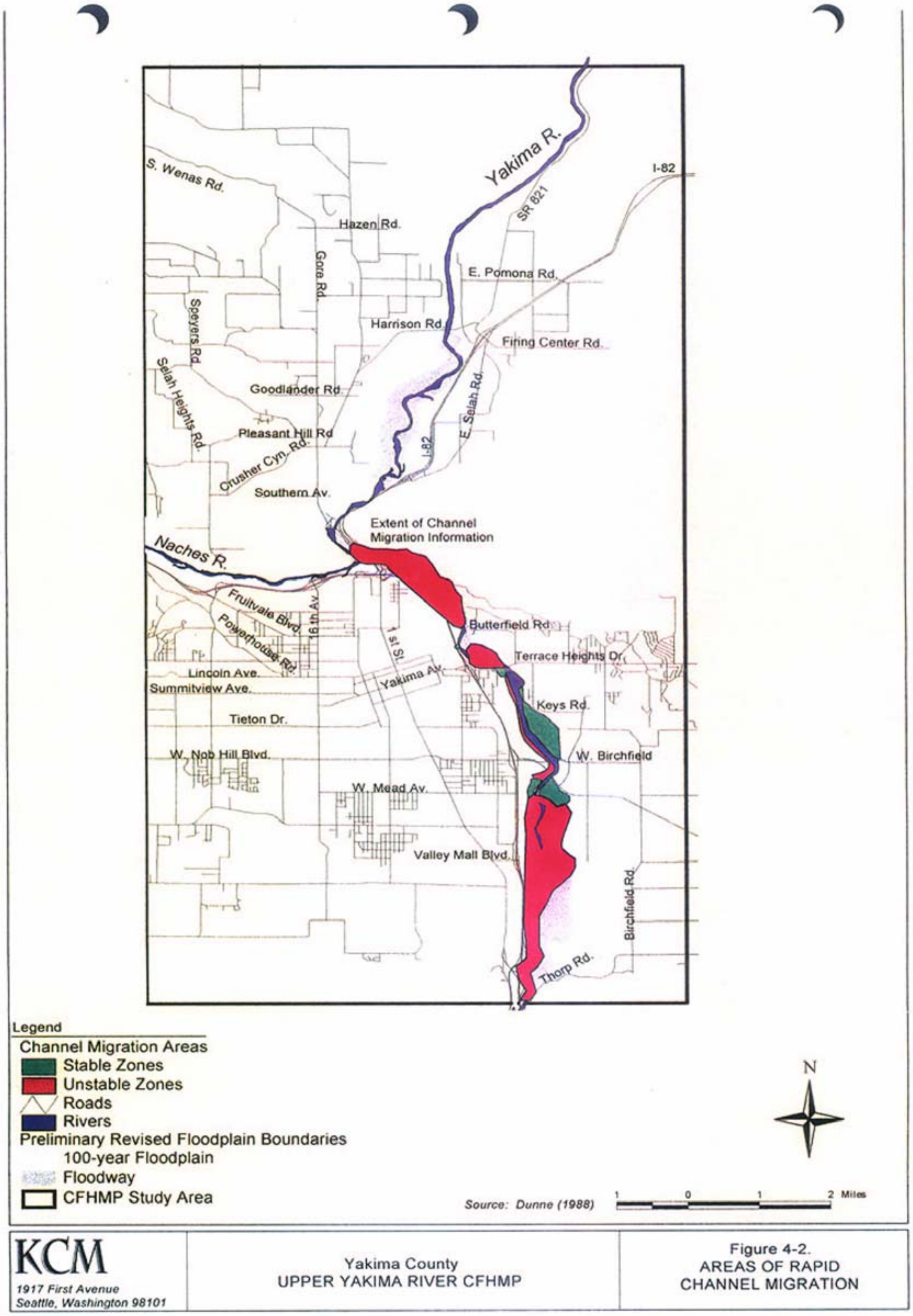


Figure 12: Areas of Rapid Cannel Migration

The second tool for assessing the relative risk of bridge location in terms of channel migration is through stream power analysis. Noted Geomorphologist Mark Lorang, of University of Montana, has used such an analysis to identify those locations where the river has the greatest erosive and avulsive power in order to assess the restorative potential of comparative reaches. Conversely the same analysis can be used to evaluate the relative risk of erosion and avulsion for comparative bridge locations. This report will use both analyses to assess risk to bridge locations as well as restorative potential for the various alternatives.

<u>Summary Conclusion</u>

The reaches comprising the project area are extensively levied. These levees provide varying levels of protection the level of protection provided diminishes dramatically South of the existing alignment. Due to this, extreme channel constriction, increased channel and water surface slope, and the presence of gravel pits immediately outside the Levee system, flood and avulsion risk increase dramatically as well. Because the channel is held in place, the dis-equilibrium in bedload and hydrodynamics is exacerbated in the project area. This dis-equilibrium has become so pronounced that the area experiences extreme channel scour at the current bridge crossing, while simultaneously experiencing severe bed aggradation above the floodplain just upstream of the current alignment **(*See Figure 11*)**

So long as the current situation remains in place, avulsion and flood risk and degradation of floodplain functions will tend to increase. This trend will drive human response in the direction of more emergency measures to protect existing infrastructure. Thus a trajectory of increased risk, cost, and intervention that precludes restoration options is forecast if existing conditions are allowed to prevail. All is not lost for this area however, the latest research *(Stanford, Lorang; et al 2002)* point to the project area as having enormous restorative potential due to the amount of stream power present in the project area, and the pivotal position it occupies in the sub-basin with regard to hyporheic function and its relationship to biotic productivity *(Stanford; et. al., 2002)*. If baseline conditions for the project area are to be improved in the Yakima River as a whole, these researchers conclude that this is the place to start (ibid). If any meaningful restoration in the reaches of the project area is to be accomplished, normative floodplain functions must be restored. Chief among these are floodplain storage, ground/surface water interface (hyporheic functions), and channel migration ability. The key here lies in the assessment of potential relocation of levees and other infrastructure to allow restoration of these functions. Because of its location in a pivotal area of the sub-basin, the floodplain implications related to the replacement of the SR 24 Yakima River Bridge project form an important aspect of any such assessment. Hence, the need for this report. In addition, the degradation of floodplain functions have also been shown to be driving increased flood and avulsion risk, particularly in areas where gravel pits occur in close proximity to inadequate levees. Any assessment of the restorative potential of the reaches encompassing the project area must address both environmental and flood hazard risk factors associated with these features.

<u>Blue Slough</u>

The original design considerations for this project did not anticipate the potential removal of levees, as the local desire to explore it has not yet evolved into a change in floodplain management policy. Despite major channel modification, Blue Slough is an important geomorphic feature of the Yakima River floodplain. If this analysis is to consider the potential for floodplain restoration for the various project alternatives, then the potential for re-establishing Blue Slough as part of the active floodplain must be considered. If levees on the East bank were set back then hydraulic conditions for Blue Slough would change markedly. Increased peak flow, channel migration, as well as increased backwater could result depending on the alternative implemented. As such, it is likely that the proposed crossing of the slough will have to be expanded to accommodate more normative conditions. A flood model and backwater analysis will have to be prepared for any alternative that reconnects Blue Slough to the active floodplain. The hydraulic analysis for this element as well as any other element for alternatives that involve levee alterations should be carried out as part of a comprehensive preparation of a flood model to establish new Base Flood Elevations (BFE's). Setting back levees would change hydraulic conditions to such an extent that existing analyses, BFE's cross-sections, etc., would no longer be reliable.

The size and type of system that will be used to convey Blue Slough under all alignments has yet to be designed and will depend, in part upon final floodplain analysis hydraulic code requirements in the floodplain policy. Several options are being reviewed; from extending the proposed Yakima River Bridge over Blue Slough to creating a separate bridge structure over Blue Slough, as well as the installation of large culverts in this area.

Blue Slough is an important side channel of the Yakima River and has shoreline jurisdiction requirements. The original design work for this project, and existing SR 24 alignment to the south, did not consider the potential for restoration of the floodplain, thus the existing hydraulic conditions that are highly controlled and disconnected from the active floodplain. While the slough is used for irrigation, it is still an important geomorphic feature to the Yakima River floodplain. If this report is to analyze the project's potential to accommodate, or at least not preclude the emerging local floodplain management vision that includes a strong restoration component, then the analysis must include consideration of impact minimization and restorative potential with regard to Blue Slough. Furthermore, the possibility of increased peak flows in Blue Slough associated with future restoration activities also warrants further consideration of the hydraulics and design of the highway crossing from a flood safety standpoint. Generally, if Blue Slough is to be considered as part of a future restoration plan, much larger peak flows through the Slough must be anticipated in design considerations. Conclusions drawn from such considerations will logically trend toward increased span size for Blue Slough crossings under all of the build alternatives.

Hydrology/Hydraulic Analysis

A backwater analysis was prepared in 2002, for a north alternative 1000- foot bridge span *(See Appendix B)* The analysis indicated that despite using larger piers for the replacement span, a reduced number of piers would result in a slight reduction in backwater surface elevations (0.42 feet at normal annual high flow, 0.8- foot at the 100- year flow of 56,300cfs) from the existing bridge, if pier spacing recommendations in the analysis were followed. This would tend to reduce velocities and scour just below the alignment.

Extrapolation of this analysis to a similar span on the southern alignment cannot be accomplished using existing data. Additional data must be gathered to establish cross sections at the bridge site and downstream, and establish boundary hydraulic conditions as model parameters. These must be drawn from new channel cross-sections, levee profiles, as well as topographic and hydrographic data. This analysis could then be completed with a modified floodplain configuration being evaluated by the YCFCD.

Similarly, the long span alternatives on either alignment will need additional modeling to assess potential backwater effects. New floodplain cross-section profiles based on levee setback scenarios must be developed, with attendant boundary conditions for each alternative. A model run simulating flood conditions with setback levees must then be developed. This should be a "2D" model based on two-foot contours tied in with new channel cross-sections in order to adequately model storage and complex routing of floodwater outside of the main channel. This will indicate reliable base flood elevations for levee setback scenarios that could be applied to a backwater analysis for a long span bridge. *(See Appendix C)*

The Yakima County Flood Control Zone District is in the process of obtaining LiDAR (Light Detecting And Ranging) topographic data that will meet the accuracy standard for this type of detailed flood modeling. *(See Appendix C)*. Without reliable base flood elevations, it is not possible to model the potential backwater effect of the long span bridges under various restored conditions. As selection of these alternatives hinges in part upon the degree to which the various alternatives accommodate or preclude floodplain restoration, modeling long span bridge effects should be carried out in close cooperation with floodplain restoration modeling and planning efforts. Not only is the channel cross section markedly different if more of the historic floodplain is reconnected, but the boundary conditions under a set back levee scenario would be completely different as well.

Developing a flood model capable of simulating peak flows for levee setback scenarios is a necessary step in developing any future floodplain restoration project involving levee alteration or removal. If a long span bridge, either along the south or north alignment is selected as a preferred alternative than its backwater effects should be coordinated with overall flood modeling efforts. Hydrologic trend implications for backwater analysis will be discussed for each alternative in the body of this report using the analyses available to date. However, the limitations of extrapolating data from one analysis to another hypothetical alignment must be recognized.

This discussion has focused on backwater effects and the implications for streampower, erosion, and avulsion, because these are hallmarks of the existing constricted channel conditions, which lies at the root of the dis-equilibrium that drives the scour, erosion, and flood/avulsion risks that this project must address. In the event that the bridge is lengthened however, then the effects of increased conveyance must be addressed as well. Care must be taken so as not to convey too much additional water downstream thus worsening downstream flooding conditions. This is particularly the case south of the existing alignment where the levees cannot handle the same capacity as those upstream. This reinforces the fact that the bridge length and potential restoration of flood storage a capacity are inherently linked. Just as the bridge must be lengthened in order to accommodate floodplain restoration, additional storage must be provided if conveyance through the project area is to be increased resulting from an increased span. As with backwater effects, downstream conveyance effects on base flood elevations must be carefully modeled with storage and downstream channel capacity limitations in mind as part of any potential floodplain restoration scenario.

5.0 PROJECT ALTERNATIVE ANALYSIS

Alternative 1 - No Build

5.1.1 Existing Baseline Floodplain Conditions

Floodplain function is largely determined by the degree to which the floodplain is connected to the river, both surficially, and hydrologically. The Union Gap sub basin has lost 60% of its original floodplain (*Ubelacker, 2000*). Slope and stream power analyses *(Lorang*) indicate that this reach is highly prone to erosive action and river avulsion *(Lorang, 2002*), and that the erosive and avulsive potential of the lower reach is much higher than the middle reach. In his analysis of the Yakima, Lorang used stream power and shear stress to estimate the potential for the river to do erosive and avulsive work in various reaches. **Figure 13** shows the analysis for stream power. In this graphic the larger and darker the orange coloring, the higher stream power was measured above the statistical mean. The analysis clearly indicates that the existing structure is located in the area of highest stream power, which occurs at the beginning of the lower reach in the project area. The outlined rectangular area just below the bridge in (***See Figure 13***) depicts the area of highest stream power. Lorang's conclusion is that the lower reach has excellent potential for doing erosive and avulsive work. Thus, this reach is superior for floodplain restoration. This also indicates that from a hydrological and channel stability perspective it is not the best location for in-stream structures, such as bridges, particularly those that are not designed to withstand or accommodate essential channel changes, as they will inevitably encounter more force and erosive channel change than locations in the system where stream power is not as great.

Here the channel is not only highly constricted, there is a break in slope that increases water velocity. This break in slope is apparent in the topographic contours west of the active channel ***(See Figure 14*)**. Constriction of the floodway by levees and the bridge exacerbates this slope within the active channel inside of the levees.

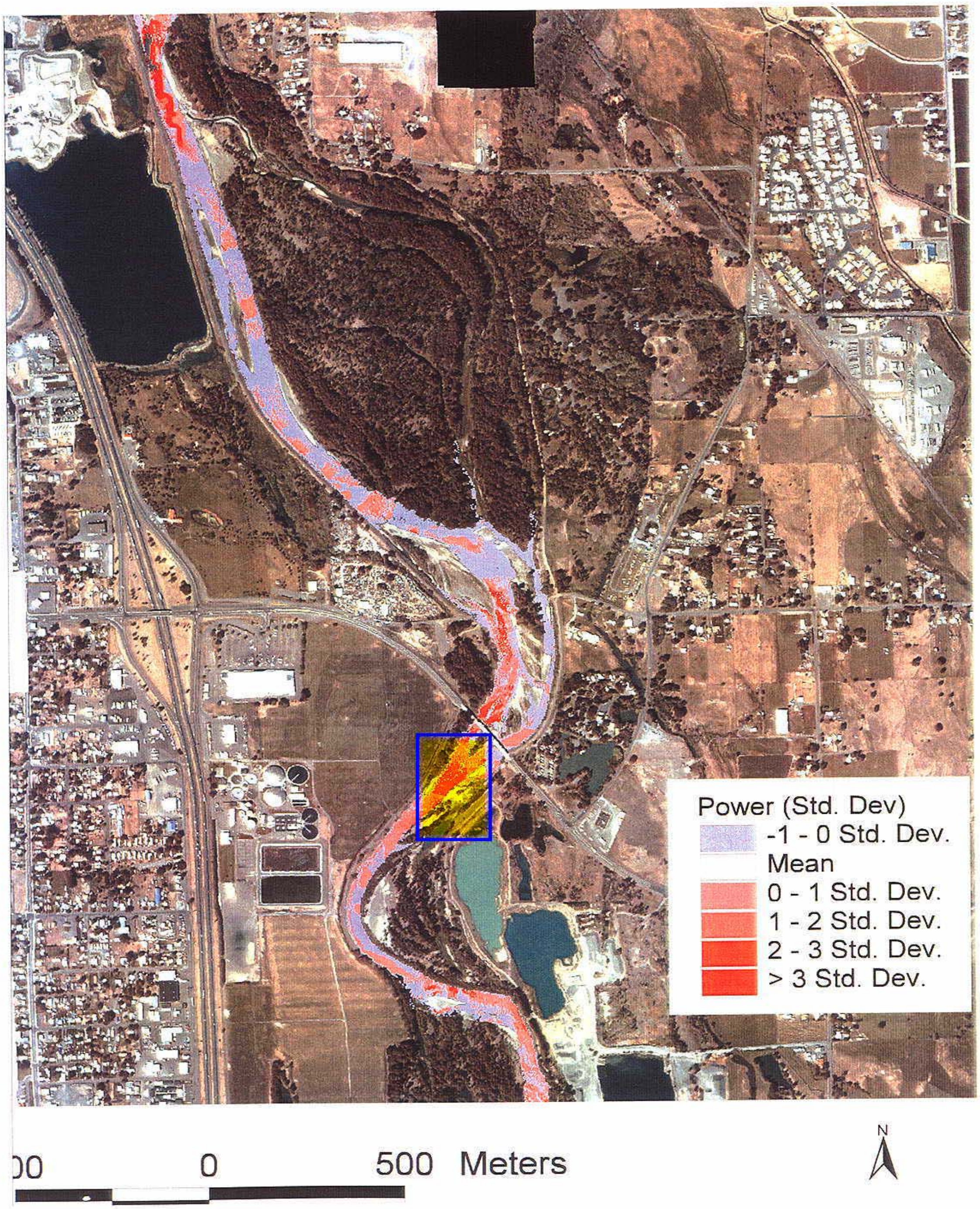


Figure 13: Stream Power Analysis

Figure 14: Modeled Flood Plain Topography

This continues to exacerbate as scour increases as a result of increased velocities. While this is occurring downstream more and more sediment falls out in the reach upstream due to the backwater and artificial hydraulic head created by the channel constriction and the bridge piers. This further reinforces the imbalance of sediment transport between the reaches, in this way a vicious cycle is set into motion.

The cumulative result of these interacting factors has been exacerbated environmental degradation, erosive damage to both levees and transportation infrastructure, and increased flooding and river avulsion risks to the local population within and downstream of the project reach due to aggradations of the floodway.

5.1.2 Risk/Liability of Alternative

Under a No Build Alternative, the degraded baseline floodplain conditions that have resulted in scour and bank erosion problems at the existing bridge site would continue to degrade floodplain function. As such hydrogeologic conditions for the structure are likely to deteriorate further as well. It is probable that this will necessitate additional attempts to protect the bridge through emergency measures. Furthermore, as repeated previous efforts to temporarily alleviate the problem have failed it is likely that future measures will have to be even more intrusive, extensive, and expensive. These will each have additional detrimental environmental effects. Future measures would likely include the placement of pilings in the active channel adjacent to the spread footings of the existing piers. A reinforced bond beam or pier cap would then be poured to hold the piles and piers together. (*Kerry Grant P.E., Pers Com*) Reinforcing the piers in this manner would place additional structures in the floodway increasing backwater effect, and exacerbating scour at and immediately below the pier locations while these measures would be a highly likely probability under the No Build alternative, as the reach continues to degrade, there is a small, but distinct, risk of catastrophic failure of the structure (either the bridge itself, the levees, and/or the bridge approach and abutments of which it has become a component) under extreme flood conditions. Under the No Build Alternative, this risk will increase over time. It is important to recall here that at peak flows of 56,000 cfs in 1996, levees immediately south of the existing bridge nearly failed due to overtopping. Such a failure would have had catastrophic results not only for the community, but would have probably damaged or destroyed the SR24 bridge and/or its approaches due to the change in channel elevation and the ensuing avulsion associated with capacity of the Newland pits downstream of the bridge *(Appendix D*, also *(Freudenthal Pers Comm).*

5.1.3 Potential Floodplain Restoration/Levee Removal

The No Build Alternative maintains existing constricted channel conditions. As such opportunities for floodplain restoration are precluded under this alternative. Similarly, no levee removal options are facilitated by a No Build option. The existing bridge location marks the delineation line between the federal levee system north of the alignment, which provides certified 100-year protection, and the levees south of the alignment, which provide only marginal protection. In the event of failure of downstream levees, the SR 24 roadway would serve as a floodplain partioning levee. Ostensibly, this would protect the KOA campground, propane distributor as other businesses and residences north of the route from backwater flooding effects.

The problem here is that the highway is not designed to function as a levee. The route has neither the heights nor construction to qualify for certification as a PL-99 levee.

5.1.4 Direct Impacts

Hydrology

Under a No Build Alternative Hydrogeology of the project reach would continue to degrade due to baseline conditions of extreme channel constriction low ability to provide for sediment transport, and floodplain disconnectivity associated with current levee and bridge configuration.

Additional hydrogeologic impacts to the channel may result from emergency protection measures as referred to above however these type of impacts pale in comparison to the systematic disconnection of the floodplain which has set the baseline for this reach.

Fill

Under a No Build Alternative, no additional fill would be placed in the floodplain as a result of this project. If baseline floodplain functions are allowed to continue the current downward trajectory additional measures to shore up levees in the project reach should be anticipated. As the reach continues to aggrade and levees experience damage in the future, additional fill placed on the riverward side of the levees by natural or human activities could further exacerbate channel constriction, backwater effects upstream of the fill, increased scour in the hydraulic shadow of the bridge, and increased avulsion risk in areas within and downstream of the aggraded floodway.

Erosion

Under the No Build Alternative, bank erosion and scour will both continue, and probably worsen in the project reach so long as the predominate channel condition remains highly constricted. As mentioned above, additional emergency reinforcement may result in the placement of additional material or structures in the floodway. This will increase backwater effects upstream, water velocities at the structure, and scour downstream. The magnitude of these impacts would depend upon the type of emergency measure proposed. These effects are anticipated to be minor when compared with those of the levee systems that dominate the reaches of the project area, or to the catastrophic failure of the infrastructure they would need to protect.

5.1.5 Indirect Impacts

Levee Removal

A No Build Alternative precludes potential floodplain restoration. The existing bridge configuration would not allow a levee setback upstream because the existing abutments form a component of the levee system itself. In addition, the road prism stretching east from the bridge toward Birchfield road does not appear to be high enough or protected enough to withstand flooding pressures if the river levee upstream was removed (this would have to be modeled to determine a new base flood elevation for the levee setback). Lastly, the critical scour problems at the existing bridge piers represent an additional point of vulnerability that may preclude any restoration in the vicinity if it results in head-cutting, rapid re-distribution of sediment loads or other abrupt hydrogeologic changes that may harm the already vulnerable structure.

Floodplain Acquisition

Since the No Build Alternative would preclude most floodplain restoration in the vicinity of the SR24 Bridge it is not anticipated that substantial floodplain acquisitions would be required if appropriate.

5.1.6 Cumulative Impacts

Gravel Pits/Head-Cutting Potential

The potential for ecological and infrastructure damage from river avulsion into the gravel pits has been cited as a concern by County officials, prominent academic researchers who have studied the river, and WSDOT floodplain management staff. The risk here is that if the river recaptures the pit sites, then the thalweg and sediment bedload, will be entrained into the pits. This will rob the river of sediment, while increasing slope and velocities at the avulsion site. The implications of this for riverine processes and flood safety are anticipated to be severe.

Head Cutting

The sudden increase in both channel and water surface slope that would result from the an avulsion of the river into the pits could possibly start a head cut traveling upstream as the increased water velocity drives the bedload to equalize the channel depth with that of the pit(s). This erosive process may travel for a substantial distance upstream, threatening the stability of any levee or other structure in its path. The distance of the head cut would depend upon the size of the pit and the length of time it takes for the entrained bedload to equalize the topographic difference between the channel and the pit floor. *(Dunne 1986 also; Freudenthal, pers comm)*

A second possible outcome of river avulsion into the gravel pits would consist of increased scour downstream due to bedload entrainment. As the river avulses into the pits they quickly fill with water and start to fill with sediment. When the water reaches the top of the pit it flows overland to find a new channel or to re-enters the old one. The water re entering the channel is thus free of sediment. Since none of the energy being generated by the flowing water is being used to transport sediment or bedload, this clean water has much more ability to erode the bed and banks of the river. Thus, erosion and channel scour increase until the carrying capacity of the thalweg is again attained, or until an additional constriction dumps the sediment load in a backwater and starts the process of bedload imbalance again. Again the extent of this outcome would be determined at least in part by the length of time it takes to equalize the topographic difference between the river channel and the avulsion site pit floor. As with the head-cutting process, increased channel scour downstream would place all levees, bridges, irrigation headworks, and other waterfront infrastructure at greater risk for erosive damage until the elevations equalize. *(Eitemiller et al 2002, also Dunne1976, and Stanford et al 2002)*

Meander Belt Migration/Sewage Treatment Outfall

The constriction of the channel within the project area combined with gradient issues between the floodway and floodplain /gravel pit elevations, and the high stream power occurrences within the project area just below the existing span all point toward an anticipated tendency for the channel to migrate to the east if the levees along the east bank are removed or set back. This raises concerns with regard to the outfall for the City of Yakima Sewage Treatment Plant, which discharges to the river at approximately RM 110.5. The NPDES permit for the sewage treatment plant is predicated upon discharge into the river in an approved mixing zone in order to dilute the effluent. If the channel migrates to the east, the outfall could lose its mixing zone violating the city's NPDES permit, As the No Build Alternative precludes restoration of the floodplain in the project area, the channel will not be allowed to meander.

<u>Alternative 2 - South (Low Profile) Alignment</u>

5.1.7 <u>Affected Environment</u>

The Project Area is defined geomorphically, as the Middle and Lower Reaches of the Upper Yakima Sub-basin. Reduction in meander amplitude and channel complexity due to constriction, and a break in slope as described by Lorang in his stream power analysis demark the knick point between the reaches. *(Lorang 2002)*. The Project reach is characterized by extreme channel constriction, an aggraded perched active channel, extreme scour and resultant moderate channel incision at the existing bridge site along with increased slope and water velocities compared to reaches either upstream or downstream. Below the scour area in the lower reach the active channel is aggrading. Land development near the river has resulted in additional channel constrictions with an estimated 60 percent reduction of the original floodplain area. From a floodplain function standpoint, the project reach is among the most degraded in the Yakima Sub-basin. As described above the loss of function in this reach is chiefly due to channel constriction from levees. This condition has been getting progressively worse for decades.

5.1.8 <u>Risk/Liability</u>

The replacement of the scour critical piers on spread footings with drilled-shaft pilings proposed for the replacement structure will greatly reduce scour risk for a replacement span. There are however several other erosion and avulsion risk considerations that must be taken into account. These risks include other WSDOT infrastructure as well as infrastructure belonging to local agencies and private entities.

5.1.9 <u>Potential Floodplain Restoration/Levee Removal</u>

An elevated short span along the existing alignment offers minimum, if any, potential for floodplain restoration. Most of these potential floodplain restoration options exist along the left (East) bank downstream of the existing alignment. The optimum restoration of existing channel sinuosity that can be attained under Alternative 2 occurs adjacent to the left bank highway abutment where the existing levee may be tapered back from the Yakima River channel. This will help reduce velocities and scour potential at the bridge site. Below the bridge the levee should taper back along an even sinuous curve to a point where it parallels the highway (***See Figure 15***) from this point, the set back should parallel the highway until veering gradually to the south, again following a smooth curve that matches the sinuosity of the river channel. Finally the levee ties in with the proposed setback along the Central Premix Access Road (*Gravel Pit EIS; David Brown & Associates, 20002*). Because of the potential for increased ecological damage and increased damage risk to infrastructure, if there is to be any restoration of floodplain in this vicinity, then detailed (two foot contours) topographic data for both the channel and gravel pit areas must be gathered and analyzed for avulsion risk. Based upon the findings of this data the gravel pit flood elevations should be brought up to within six to eight feet of grade *(Lorang2002, also Freudenthal , Pers Comm,. and Park Field Obs 2002.)*

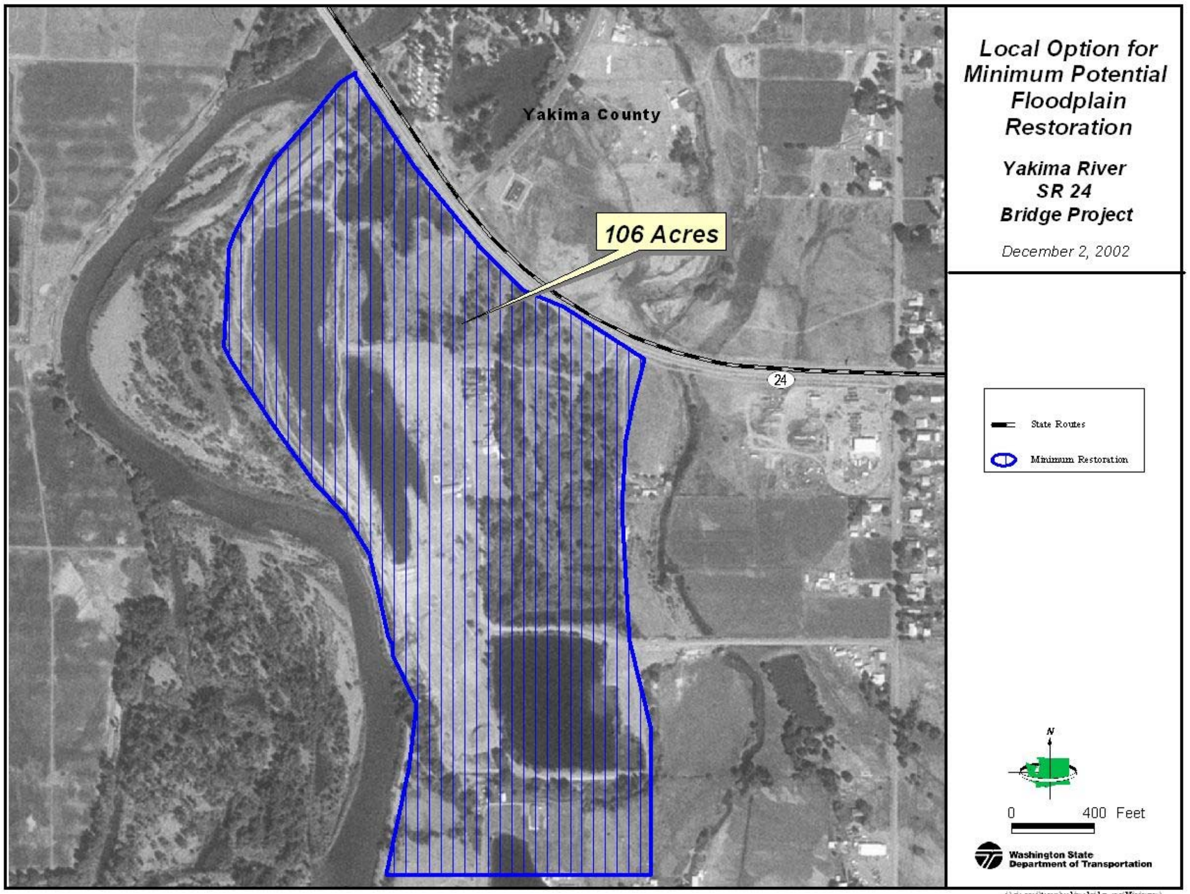


Figure 15: Alternative 2 Minimum Potential for Floodplain Restoration

5.1.10 Channel Stability

According to channel migration analysis presented in the Yakima River CFHMP, the west abutment for this alternative would be located in an unstable channel zone *(**See Figure 12**)*. The bank in this location has been receding since the channel migration resulting from the 1996 flood event *(Freudenthal, Pers Comm, 2002).* In addition, Yakima County is considering alterations of the levees in the reach, including FED RB4 situated on the right bank, upstream of the existing bridge location.

Due to the background data and current regulations found in Section 3.8, Channel Migration, it is recommended that if Alternative 2 becomes the preferred alternative for project action that mitigation involve a setback of the west side levee to help recapture an important side Yakima River channel running through a portion of a wrecking yard just north of the existing span on the west bank of the river. In light of these risk factors, this report also recommends that the bridge abutment be set back beyond the unstable zone as delineated in the CFHMP.

5.1.11 Direct Impacts

The levee and the highway must cross Blue Slough, a side channel to the Yakima. Blue Slough is crossed on the existing route with a five-foot diameter culvert. The original design considerations for this project did not include the possibility of re-connecting Blue Slough to the active floodplain. As such, several technical hydrological, and regulatory issues must be addressed with regard to the crossing of Blue Slough. If normative floodplain conditions are to be restored to the area immediately south of the existing alignment then increased backwater effects can be expected in Blue Slough. The questions is, should the baseline isolation of Blue Slough continue or be modified by design to enhance habitat and floodplain function. This is one of the trade-offs between environmental restoration and socio-economic impact that must be addressed by local jurisdictional authorities in an overall revision of their floodplain management plan as restoring Blue Slough to the active floodplain may increase flooding risk for the KOA Campground, as well as residences and businesses along Blue Slough to the North of the existing alignment. This area is impounded by SR 24 on the south, Moxee Road on the north, Levee PL-99YSEG7A to the west, and Blue Slough to the east. Backwater flooding into this impoundment would be inhibited from receding as sheet flow as flood levels fall. This would lengthen flood durations within the impoundment resulting from backwater flooding up Blue Slough. This trend would become more pronounced as bedload is redistributed in the restored floodplain, raising the restored floodplain in relation to the floor elevation of the impoundment. While a floodgate could prevent backwater flooding through the levees and road via Blue Slough, this presents regulatory problems that preclude it as an option. According to the National Marine Fisheries Service, Lower Columbia Steelhead, which are listed as threatened under the Endangered Species Act occupy Blue Slough. A floodgate to prevent backwater flooding would likely preclude the species from habitat, potentially resulting in potential regulatory difficulties (for analysis of ESA related impacts please refer to the Biological Assessment for this project) *(McQueary 2002)*. With regard to potential floodplain restoration, placing a floodgate at the outlet of Blue Slough would preclude floodplain restoration involving the Slough for these reasons it should not be considered.

Hydrology/ Hydraulic Analysis

A backwater analysis was prepared in 2002 for the North Alternative 1000 foot span (See Appendix B) The analysis indicated that despite using larger piers for the replacement span, a reduced number of piers would result in a slight reduction in backwater surface elevations (0.42 feet at normal annual high flow, 0.8 foot at the 100 year flow of 56,300cfs), if pier spacing recommendations in the analysis were followed. This would tend to reduce velocities and scour just below the alignment.

Extrapolation of this analysis to a similar span on the southern alignment cannot be accomplished using existing data. A new backwater analysis must be performed and used as part of the design if this alternative is selected. Additional data must be gathered to establish cross sections at the bridge site and downstream, and establish boundary hydraulic conditions as model parameters. These must be drawn from new channel cross-sections, levee profiles, as well as topographic and hydrographic data. Levee heights are of particular significance here when considering boundary conditions for the Southern Alternative. As noted above the levees upstream of the Southern Alignment are part of the federal levee system and provide 100-year protection. The levees south of the existing alignment however only provide 5 to 25 year protection. This change dramatically reduces the carrying capacity of the floodway between the levees, thus changing the backwater effect even if the same size bridge pier structure were used.

Another factor that must be taken into account is the location of the levees. If the levees remain in their existing locations then the balance between backwater and conveyance must be carefully assessed in order to avoid overtopping the downstream levees. On the other hand, if the East bank levees are moved back from the riverbank then additional storage will be provided the river's carrying capacity and conveyance will be increased and backwater effect will decrease.

This discussion has focused on backwater effects and the implications for streampower, erosion, and avulsion, because these are hallmarks of the existing constricted channel conditions, which lies at the root of the dis-equilibrium that drives the scour, erosion, and flood/avulsion risks that this project must address. In the event that the bridge is lengthened however then the effects of increased conveyance must be addressed as well. Care must be taken so as not to convey too much additional water downstream thus worsening downstream flooding conditions. This is particularly the case south of the existing alignment where the levees cannot handle the same capacity as those upstream. This reinforces the fact that the bridge length and potential restoration of flood storage a capacity are inherently linked. Just as the bridge must be lengthened in order to accommodate floodplain restoration additional storage must be provided if conveyance through the project area is to be increased resulting from an increased span. As with backwater effects, downstream conveyance effects on base flood elevations must be carefully modeled with storage and downstream channel capacity limitations in mind as part of any potential floodplain restoration scenario.

Lastly the backwater analysis should include characterization of potential backwater flooding northward along Blue Slough under this alternative.

<u>Fill</u>

The proposed bridge length and the amount of fill required are interdependent. Generally, the longer the bridge, the lower the fill requirement. The proposed lane widening and elevation of the roadway along a South Alignment would incorporate the existing right of way fill, minimizing the amount of new fill required for alternatives configured along a Southern Alignment. The existing footprint encompasses approximately 50 percent of the required new footprint, (depending upon height required to be above the 100-year base flood elevation, and the length of the span. For a short span (1000 feet), an approximate total footprint of 22.38 acres would be required of which 11.19 acres would be new fill footprint in the floodplain. For a long span (2200 feet, a total roadway footprint of approximately 16.29 acres would be required of which 8.15 acres would be new fill within the floodplain.

<u>Erosion</u>

While a 1,000 foot span on the Southern Alignment would represent an approximate 40 percent improvement in active channel cross section width from existing conditions, the heightened streampower and resultant erosive/avulsive potential at this location would still result in ongoing sediment transport imbalance within the project area. Channel bed scour problems and imbalance between erosive and depositional reaches of the project area would continue, albeit at a somewhat reduced rate. While this would have ongoing negative impacts for riverine function, thus precluding aspects of floodplain restoration such as levee setback, the new bridge abutments and pilings can be located and constructed in such a way as to negate the scour impacts that are threatening the current structure.

5.1.12 Indirect Impacts

Levee Removal

As described above, a setback of the existing levee along SR 24 as far back as Blue Slough would increase the risk of backwater flooding northward of the existing alignment via Blue Slough. Currently the lower segments of the slough are behind levees, gravel pits, and other features that disconnect it from the floodplain. If levees were set back along SR 24 under this alternative, then Blue Slough would receive both a flood pulse through its upstream headwork, (RM 115) and a backwater flood pulse from downstream of SR 24. If flooding is increased north of the existing SR 24 alignment as a result, then properties in that vicinity may have to be bought out by local entities or FEMA to alleviate flooding risk, if the area is included as part of a Floodplain Restoration Plan.

Floodplain Acquisitions

As described above, the potential for backwater flooding northward along Blue Slough depending upon severity. Estimates drawn from site observations and aerial photographs indicate that 15 to 20 permanent structures may be affected depending upon flood magnitude and degree of connectivity. *(Park Field Obs 2002)*

Analysis of potential backwater effects on Blue Slough must form an essential portion of the hydraulic analysis for this alternative if pursued as the potential impact to properties and structures situated between Blue Slough and the Yakima River must he modeled to determine public safety risks, and potential acquisition locations.

5.1.13 Cumulative Impacts

Gravel Pits/Head-Cutting Potential

The potential for ecological and infrastructure damage from river avulsion into the gravel pits has been cited as a concern by County officials, prominent academic researchers who have studied the river and WSDOT floodplain management staff. The risk here is that if the river recaptures the pit sites, then the thalweg and sediment bedload, will be entrained into the pits. This will rob the river of sediment, while increasing slope and velocities at the avulsion site. The implications of this for riverine processes and flood safety are anticipated to be severe.

Head Cutting

The sudden increase in both channel and water surface slope that would result from the an avulsion of the river into the pits could possibly start a head cut traveling upstream as the increased water velocity drives the bedload to equalize the channel depth with that of the pit(s).

This erosive process may travel for a substantial distance upstream, threatening the stability of any levee or other structure in its path. The distance of the head cut would depend upon the size of the pit and the length of time it takes for the entrained bedload to equalize the topographic difference between the channel and the pit floor. *(Dunne 1976 also; Freudenthal, pers comm. 2002)*

A second possible outcome of river avulsion into the gravel pits would consist of increased scour downstream due to bedload entrainment. As the river avulses into the pits they quickly fill with water and start to fill with sediment. When the water reaches the top of the pit it flows overland to find a new channel or to re-enters the old one. The water re entering the channel is thus free of sediment. Since none of the energy being generated by the flowing water is being used to transport sediment or bedload, this clean water has much more ability to erode the bed and banks of the river. Thus, erosion and channel scour increase until the carrying capacity of the thalweg is again attained, or until an additional constriction dumps the sediment load in a backwater and starts the process of bedload imbalance again. Again the extent of this outcome would be determined at least in part by the length of time it takes to equalize the topographic difference between the river channel and the avulsion site pit floor. As with the head-cutting process, increased channel scour downstream would place all levees, bridges, irrigation headworks, and other waterfront infrastructure at greater risk for erosive damage until the elevations equalize. *(Eitemiller et al 2002, also Dunne1976, and Stanford et al 2002)*

<u>Meander Belt Migration/Sewage Treatment Outfall</u>

The constriction of the channel within the project area combined with gradient issues between the floodway and floodplain /gravel pit elevations, and the high stream power occurrences within the project area just below the existing span all point toward an anticipated tendency for the channel to migrate to the east if the levees along the east bank are removed or set back. This raises concerns with regard to the outfall for the City of Yakima Sewage Treatment Plant, which discharges to the river at approximately RM 110.5. The NPDES (National Pollutant Discharge Elimination System) permit for the sewage treatment plant is predicated upon discharge into the river in an approved mixing zone in order to dilute the effluent. If the channel migrates to the east, the outfall could be left without its mixing zone, and thus be out of compliance with the NPDES permit. An in depth examination of alternative outfall and treatment options must be carried out in order to develop and implement measures to address this potential before any setback of levees is attempted. Potential strategies may include selective breaching of east bank levees to allow side channels to form while keeping the thalweg entrained, moving the outfall to a different location, changing the outfall to a canal or created wetland application. Examination of these strategies lies beyond the scope of this analysis, however it is essential that such examinations be carried out.

<u>Yakima County Road Project (South 33rd Street)</u>

The current design calls for South 33rd Street to Cross Blue Slough near Keyes Road, and connect with the southern alignment after where Blue Slough is crossed by the current SR 24 right-of-way. This represents a considerable fill impact on segments of the floodplain where restoration is facilitated by this alignment. Therefore, this report supports the county's decision to relocate 33rd street to the vicinity of Riverside Road, so that potential floodplain restoration areas and Blue Slough are avoided.

Alternative 3 - South (Raised Profile) Alignment

5.1.14 Affected Environment

As mentioned earlier in this paper, the overarching goal of floodplain restoration within this project context is to strive for a balance between functional environmental restoration, flood safety, and infrastructure improvement and protection. While some of these issues drive each other, (increased flood storage and habitat creation for example) others represent a tradeoff between socioeconomic values *(*open floodplain versus developed floodplain for example*)*. This Floodplain Consistency analysis presents the potential restored floodplain for each alternative in terms of minimum, moderate, and maximum levels of restoration. By approaching the analysis in this manner a more flexible analysis of each alternatives results. This will allow the Floodplain Consistency Analysis to function as background information for consideration of socioeconomic factors that lie beyond the scope of this report.

5.1.15 Risk/Liability

The replacement of the scour critical piers on spread footings with drilled-shaft pilings proposed for the replacement structure will greatly reduce scour risk for a replacement span. There are however several other erosion and avulsion risk considerations that must be taken into account. These risks include other WSDOT infrastructure as well as infrastructure belonging to local agencies and private entities.

5.1.16 Potential Flood Plain Restoration/Levee Removal

Alternative 3, South Raised Profile does not preclude potential floodplain restoration by local, state, or federal agencies. However, there are many issues that are beyond the scope of the WSDOT SR 24 Highway action that need to be further addressed and evaluated. For instance a flood model simulating removal of the existing levees and establishment of setback levees must be done in order to calculate new Base-Flood-Elevations and freeboard requirements for the road. Blue Slough limits the ability to provide backwater protection to properties north of SR 24 and below the base flood elevation.

The elevated longer bridge span of Alternative 3 along the existing alignment offers moderate to maximum potential for floodplain restoration. Most of this exists along the East bank downstream of the existing alignment. The optimum restoration of channel sinuosity can be attained under this alternative by beginning to taper back the East bank levee at, or just above the bridge alignment. This will help reduce velocities and scour potential at the bridge site. Below the bridge, the levee should taper back along an even sinuous curve to a point where it parallels the highway (***See Figure 16***). From this point, the set back should parallel the highway until veering gradually to the South, again following a smooth curve that matches the sinuosity of the river channel.

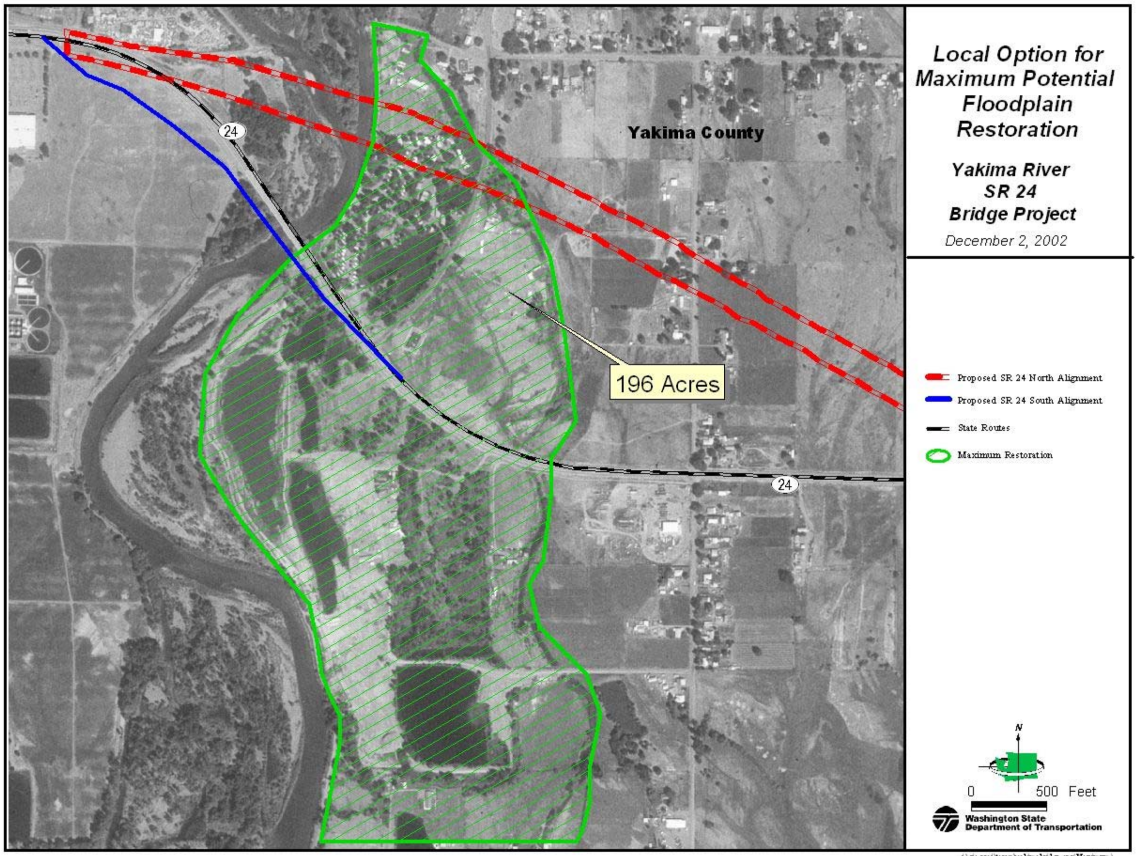


Figure 16: Alternative 3 Maximum Potential for Floodplain Restoration

To obtain maximum floodplain restoration the levee should tie in with the proposed setback levee on the east bank of Blue Slough. To obtain moderate floodplain restoration the setback levee should be located along the current gravel pit access road west of Blue Slough *(**See Figure 17**)*.

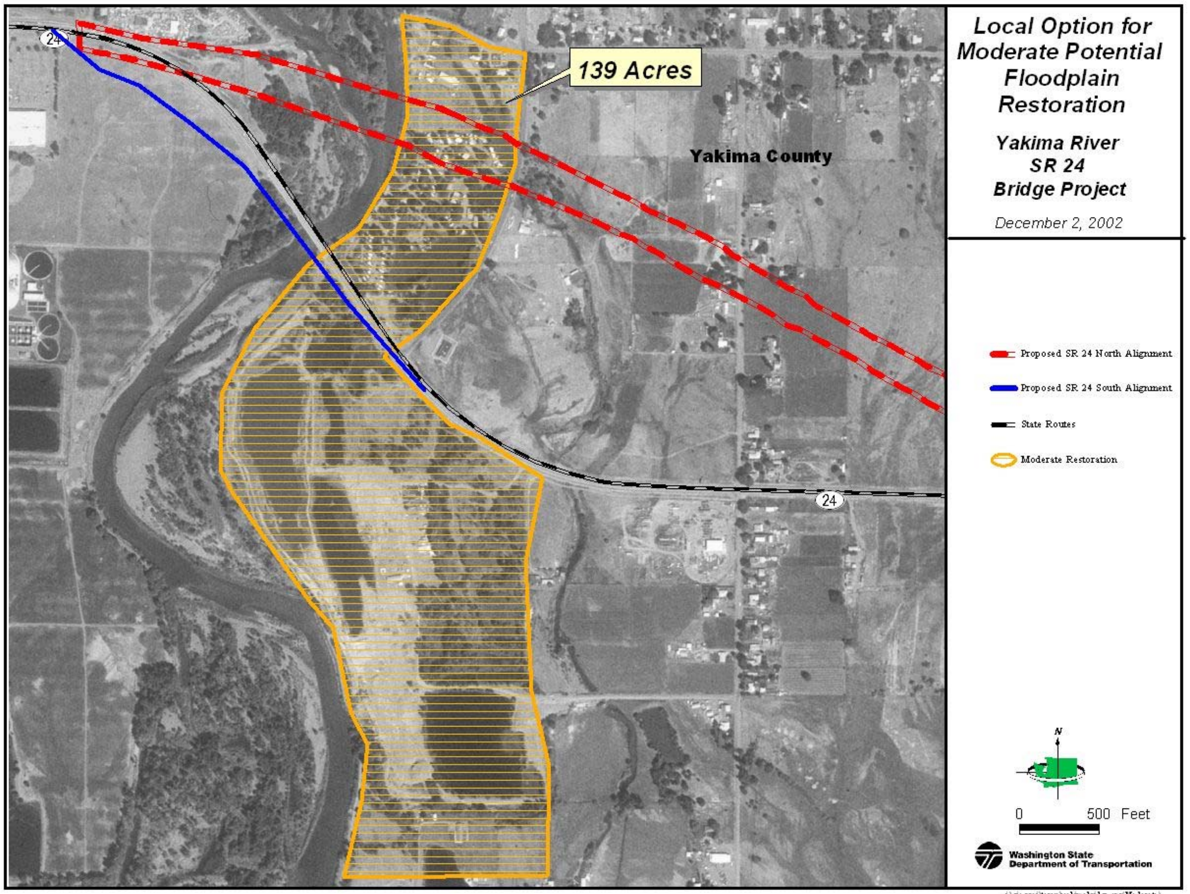


Figure 17: Alternative 3 Moderate Potential for Floodplain Restoration

5.1.17 Direct Impacts

The highway must cross Blue Slough, a side channel to the Yakima. The Slough is crossed on the existing route with a five-foot diameter culvert. The original design considerations for this project did not include the possibility of re-connecting Blue Slough to the active floodplain. As such, several technical hydrological, and regulatory issues must be addressed with regard to the crossing of Blue Slough. If normative floodplain conditions are to be restored to the area immediately south of the existing alignment then backwater effects can be expected in Blue Slough. This may increase flooding risk for the KOA Campground, as well as residences and businesses along Blue Slough to the north of the existing alignment. This area is impounded by SR 24 on the south, Moxee Road on the north, Levee PL-99YSEG7A to the west, and Blue Slough to the east. Backwater flooding into this impoundment would be inhibited from receding as sheet flow as flood levels fall. This would lengthen flood durations within the impoundment resulting from backwater flooding up Blue Slough. This trend would become more pronounced as bedload is redistributed in the restored floodplain, raising the restored floodplain in relation to the floor elevation of the impoundment.

While a floodgate could prevent backwater flooding through the levees and road via Blue Slough, this presents regulatory problems that preclude it as an option. According to the National Marine Fisheries Service, Lower Columbia Steelhead, which is listed as threatened under the Endangered Species Act, occupy Blue Slough. A floodgate to prevent backwater flooding would likely preclude the species from habitat, potentially resulting in regulatory problems (*See Biology report for ESA impact analysis*). For floodplain restoration considerations the placement of such a gate would preclude restoring floodplain functions in Blue Slough area, and thus does not accommodate the local goal of increased floodplain restoration in terms of future management of floodplain safety and ecological issues. While no floodplain acquisitions would be directly necessitated by this alternative, given the increased flooding risk form backwater flooding, and the desire of local government to maximize both floodplain restoration and flood safety, properties along Blue Slough should be bought up, and levee YSEG7A should be set back to the east bank of Blue Slough

Hydrology/ Hydraulic Analysis

Placement of a longer span is being considered in order to accommodate potential levee setbacks to provide floodplain restoration. While detailed topographic hydrographic data and extensive flood modeling of the project reaches is necessary to develop an accurate analysis of hydrogeologic impacts some general conclusions can be drawn from the existing data, given an understanding of how riverine processes have become unbalanced in the basin as the result of flood control and development activities.

Generally, a longer span and set back levees would alleviate some of the constriction created by the existing span. Setting back the levees would have an even larger effect in terms of reducing channel constriction. Constriction of the channel by bridges and levees is causational to the imbalance of sediment transport dynamics that characterize the hydraulic problems associated with the project reaches. Alleviating the constriction will have several beneficial effects in this regard.

With any alignment proposed for this project fill and bridge length is inherently connected. The bridge opening and fill quantities should be generally evaluated as per flood capacity, stream power, backwater and floodplain as per min/mod/max bridge length. Generally speaking the longer the span, the broader the channel cross-section. The broader the cross section, the more the river can migrate. A broader cross section also reduces stream power by reducing backwater and water surface slope. The goal here should be to configure the bridge to the optimum balance between reduced backwater and increased conveyance and with consideration of the increased cost for incremental benefit in terms of hydraulics, floodplain restoration, and infrastructure safety.

A backwater analysis was prepared in 2002 for the North Alternative 1000 foot span *(See Appendix B)* The analysis indicated that despite using larger piers for the replacement span, a reduced number of piers would result in a slight reduction in backwater surface elevations (0.42 feet at normal annual high flow, 0.8 foot at the 100 year flow of 56,300cfs), if pier spacing recommendations in the analysis were followed. This would tend to reduce velocities and scour just below the alignment.

Extrapolation of this analysis to spans on the Southern Alignment cannot be accomplished using existing data. A new backwater analysis must be performed if this alternative is selected. Additional data must be gathered to establish cross sections at the bridge site and downstream, and establish boundary hydraulic conditions as model parameters. These must be drawn from new channel cross-sections, levee profiles, as well as topographic and hydrographic data. Levee heights are of particular significance here when considering boundary conditions for the Southern alternative. As noted above, the levees upstream of the Southern Alignment are part of the federal levee system and provide 100-year protection. The levees south of the existing alignment in the lower reach however, only provide 5 to 25- year protection. This change dramatically reduces the carrying capacity of the floodway between the levees, thus changing the hydrologic conditions, even if the same size bridge pier structure were used.

Another factor that must be taken into account is the location of the levees. If the levees remain in their existing locations, then the balance between backwater and conveyance must be carefully assessed in order to avoid overtopping the downstream levees. On the other hand, if the East bank levees are moved back from the riverbank, then additional storage will be provided the Yakima River's carrying capacity and conveyance will be increased, and backwater effect will decrease.

Lastly, the backwater analysis should include characterization of potential backwater flooding northward along Blue Slough under this alternative.

This discussion has focused on backwater effects and the implications for streampower, erosion, and avulsion, because these are hallmarks of the existing constricted channel conditions, which lies at the root of the dis-equilibrium that drives the scour, erosion, and flood/avulsion risks that this project must address. In the event that the bridge is lengthened however, then the effects of increased conveyance must be addressed as well. Care must be taken so as not to convey too much additional water downstream thus worsening downstream flooding conditions. This is particularly the case south of the existing alignment where the levees cannot handle the same capacity as those upstream. This reinforces the fact that the bridge length and potential restoration of flood storage a capacity are inherently linked. Just as the bridge must be lengthened in order to accommodate floodplain restoration, additional storage must be provided if conveyance through the project area is to be increased resulting from an increased span. As with backwater effects, downstream conveyance effects on base flood elevations must be carefully modeled with storage and downstream channel capacity limitations in mind as part of any potential floodplain restoration scenario.

Fill

The proposed lane widening and elevation of the roadway along a south alignment would incorporate the existing right of way fill, minimizing the amount of new fill required for alternatives configured along a Southern Alignment. The existing footprint encompasses approximately 50 percent of the required new footprint, (depending upon the height required to be above the 100-year base flood elevation and the length of the span. For a short span (1000 feet), an approximate total footprint of 22.38 acres would be required, of which 11.19 acres would be new fill footprint in the floodplain. For a long span (2200- feet, a total roadway footprint of approximately 16.29 acres would be required, of which 8.15 acres would be new fill within the floodplain. These figures are based upon a review of road profile sections and orthophoto overlays of project alternatives

Erosion
Because the span for this alternative would be much wider that the current structure, the imbalance in sediment transport in this reach that has resulted in bed aggradations upstream of the existing alignment and extreme scour at and below the bridge crossing would be at least partially rectified. Therefore, it is reasonable to expect the slope, and thus the stream power to be reduced over time. This will in turn reduce erosion hazards to both bridges and levees within the project reaches

5.1.18 Indirect Impacts

Levee Removal
A long span on this alignment can only be justified if the levee system is going to be set back to restore floodplain storage and function. Restored areas should be shaped so as to mimic natural river sinuosity to the greatest extent practicable in order to gradually attenuate peak flows and restore normative storage and flow functions. Following this principle, the Levee YSEG7 should begin a taper eastward away from the floodplain from a point near Blue Slough and Keyes Road. The levee setback should then arc southeast, along Blue Slough to SR 24. South of SR 24 the Levee should Arc again to the Southeast, finally running south along Blue Slough ***(See Figure 16***).

Because of the potential for increased ecological damage and increased damage risk to infrastructure, if there is to be any restoration of floodplain in this vicinity, then detailed (two foot contours) topographic data for both the channel and gravel pit areas must be gathered and analyzed for avulsion risk. Based upon the findings of this data the gravel pit flood elevations should be brought up to within six to eight feet of grade *(Lorang Pers Comm., Freudenthal, Pers Comm, Park, Field Obs 2002)*

Floodplain Acquisitions
While no floodplain acquisitions would be directly impacted by this alternative, the indirect impacts of this alternative associated with the floodplain restoration justification described above would result in the need for floodplain acquisitions along Blue Slough, particularly between Blue Slough and the main stem Yakima River, both upstream and downstream of the existing alignment. Given the increased flooding risk from backwater effects on Blue Slough, and the desire of local government to maximize both floodplain restoration and flood safety, properties along Blue Slough should be bought up, and levee YSEG7A should be set back to the east bank of Blue Slough. A minimum of fifteen to twenty permanent structures including residences, equipment businesses, a propane gas sales facility, plus a campground for tents and RV's would be affected. If properties South of the alignment are restored to the active floodplain, backwater effects will create an impoundment north of the alignment. Therefore, if Blue Slough is to be connected to the active floodplain South of the Alignment, then the properties North of the Alignment as far as Moxee Road should be acquired for restoration as well. As stated above, the current alignment acts as a secondary levee that effectively partitions the floodplain, preventing flooding south of the highway from backwatering into populated area north of the highway.

Reconnecting Blue Slough to the floodplain and removing the filled road prism for a long span bridge eliminates the secondary protection for the properties on the east bank of the Yakima between SR 24 and the Old Moxee Road. Under these circumstances, removal or failure of the East bank levee below the existing alignment would probably result in inundation of the populated area North of the bridge. Thus potential for both risk and liability will likely increase under this scenario. **Figure 14** shows one-meter topographic contours derived from a 30-meter digital elevation model and survey data. The contour lines in the vicinity of the SR 24 crossing of Blue Slough are far apart and bisect the highway. This indicates that there is no grade control to prevent backwater flooding north of the alignment. *(Lorang 2002)*

The Bureau of Reclamation, the Yakama Nation, and Yakima County all are or have participated in floodplain acquisition activities. The authoritative lead for comprehensive floodplain acquisitions in the sub-basin should rest with Yakima County. It is they who hold the jurisdictional authority to regulate the floodplain, raise taxes through the diking district, and engage the Corps of Engineers in the necessary levee reconnaissance and floodplain modeling studies. As this data is developed, a series of minimum, moderate, and maximum floodplain restoration scenarios can be constructed and comparative analyses as to the degree of functional environmental benefit and flood storage capacity attained by each alternative. As the overarching goal here is to achieve a greater level of balance between environmental functions, flood safety infrastructure improvements and protection, and economic viability as envisaged in local floodplain management strategies. The local jurisdictional authorities affected by, and in charge of, the regulation of the floodplain lead this effort.

Finally, the Floodplain Consistency Analysis for the SR 24 project considers project impacts, potential accommodation of floodplain restoration and public safety concerns. The consideration of socioeconomic impacts from floodplain restoration is beyond the scope of this report. The formal analyses of floodplain restoration scenarios must include an evaluation of the socio-economic impacts of the proposed restoration measures on the communities that dwell in and near the project area (Yakima County, City of Yakima, City of Union Gap, and the Yakama Nation) (Yakima Regional Planning Council policy). In order to be accurate and have credibility this analysis must be led by the local jurisdictional authorities.

5.1.19 Cumulative Impacts

Aggraded Floodway

Because the floodway in portions of the project area is perched above the surrounding floodplain, avulsion risk in the context of levee setback must be addressed. The imbalanced sediment transport dynamic resulting from decades of channel constriction has built up the channel within the levees, increasing the hydraulic head. Thus the energy to drive river avulsion in the project area has been developing and growing for some time. If the levees are removed, the expression of this energy across the floodplain landscape will change markedly.

If or when the east bank levees are set back the probability that the river will migrate to the east downstream of the alignment is very likely. This potential has implications for this project in terms of possible cumulative impacts involving gravel pits located on the east bank or the river. It also has implications for the sewage treatment plant, located on the west side of the river. (This concept should be extensively evaluated prior to any project, which may relocate levees in the project area.)

Gravel Pits/Head-Cutting Potential

The purpose of analyzing a longer span alternative for this project is to accommodate local, or possible federal, interest for floodplain restoration. As described in this report and elsewhere, the restoration options focus on the east bank of the Yakima River below the bridge where the population and presence of infrastructure is less dense. The area along the east bank of the river downstream from the existing alignment has been identified in work done by Stanford, Lorang and others *(Stanford, et al 2002)* as having the greatest potential for restoration. Gravel pits belonging to the WSDOT, Yakima County, and other private owners occupy this area. The potential for ecological and infrastructure damage from river avulsion into the gravel pits has been cited as a concern by county officials, prominent academic researchers who have studied the river, and WSDOT floodplain management staff. The risk here is that if the river recaptures the pit sites, then the thalweg and sediment bedload will be entrained into the pits. If a catastrophic river avulsion into the gravel pits in the lower reach were to occur it would entrain the rivers sediment load, while increasing slope and velocities into the avulsion site. The implications of this for riverine processes, infrastructure, and flood safety can be severe. Please refer to discussion of avulsion risk in the project area description section of this report.

Head Cutting

The sudden increase in both channel and water surface slope that would result from the an avulsion of the river into the pits would start a head cut traveling upstream as the increased water velocity drove the bedload to equalize the channel depth with that of the pit(s) this erosive process could extend for some distance upstream, threatening the stability of any levee or other structure in its path the distance of the head cut would depend upon the size of the pit and the length of time it takes for the entrained bedload to equalize the topographic difference between the channel and the pit floor. *(Dunne 1976)*

A second possible outcome of river avulsion into the gravel pits would consist of increased scour downstream due to bedload entrainment. As the river avulses into the pits they quickly fill with water and start to fill with sediment. When the water reaches the top of the pit it flows overland to find a new channel or to re-enters the old one. Regardless of which, the water returns to the river much sooner than the entrained bedload, which remains entrained until the pit is filled in. The water re entering the channel is thus free of sediment. The carrying capacity of water entering the reach downstream of the avulsion is greatly increased. Thus, erosion and channel scour increase until the carrying capacity of the thalweg is again attained, or until an additional constriction dumps the sediment load in a backwater and starts the process of s bedload imbalance anew. Again the extent of this outcome would be determined at leas in part by the length of time it takes to equalize the topographic difference between the river channel and the avulsion site pit floor. As with the head-cutting process, increased channel scour downstream would place all levees, bridges, irrigation headworks, and other waterfront infrastructure at greater risk for erosive damage.

Because of the potential for increased ecological damage and increased damage risk to infrastructure, if there is to be any restoration of floodplain in this vicinity, then detailed (two foot contours) topographic data for both the channel and gravel pit areas must be gathered and analyzed for avulsion risk. Based upon the findings of this data the gravel pit flood elevations should be brought up to within six to eight feet of grade *(Lorang, Pers Comm Freudenthal, Pers Comm, Park, Field Obs 2002)*

Meander Belt Migration/Sewage Treatment Outfall

The constriction of the channel within the project area combined with gradient issues between the floodway and floodplain /gravel pit elevations, and the high stream power occurrences within the project area just below the existing span all point toward an anticipated tendency for the channel to migrate to the east if the levees along the east bank are removed or set back. This raises concerns with regard to the outfall for the City of Yakima Sewage Treatment Plant, which discharges to the river at approximately RM 110.5. The NPDES (National Pollutant Discharge Elimination System) permit for the sewage treatment plant is predicated upon discharge into the river in an approved mixing zone in order to dilute the effluent. If the channel migrates to the east, the outfall could be left without its' mixing zone, and thus be out of compliance with the NPDES Permit. An in depth examination of alternative outfall and treatment options must be carried out in order to develop and implement measures to address this potential before any setback of levees is attempted. Potential strategies may include selective breaching of east bank levees to allow side channels to form while keeping the thalweg entrained, moving the outfall to a different location, changing the outfall to a canal or created wetland application. Examination of these strategies lies beyond the scope of this analysis, however it is essential that such examinations be carried out.

Alternative 4 - North Alignment

5.1.20 Affected Environment

When considering bridge location, consideration of two interrelated geomorphic factors: channel stability, and stream power are crucial. The Yakima River CFHMP presents data categorizing areas of rapid channel migration ***(See Figure 12*** *Yakima CFHMP after Dunne, 1976)*. Location of bridge alignments in relation to these zones can be used as a tool for assessing relative risk of channel migration to the proposed structure. The west abutment of the current span lies within the unstable channel zone. Replacement abutments, should avoid this zone, regardless of alignment chosen, or the type of structure proposed. The bank here is receding, and all indications are that it will continue. In addition, Yakima County is considering modifications to the West bank levee immediately upstream to reduce channel constriction. Modifying this levee would likely reinforce this trend.

The second tool for assessing the relative risk of bridge location in terms of channel migration is through stream power analysis. Mark Lorang a noted geomorphologist, with the University of Montana has used such an analysis to identify those locations where the river has the greatest erosive and avulsive power in order to assess the restorative potential of comparative reaches ***(See Figure 13)***. Conversely the same analysis can be used to evaluate the relative risk of erosion and avulsion for comparative bridge locations. This report will use both analyses to assess risk to bridge locations, as well as restorative potential for the various alternatives.

5.1.21 Risk/Liability

The proposed alignment would require reconfiguration of the levee system along the proposed alignment. In addition the Northern Alignment directly bisects several parcels of private property ***(See Figure 18 and 19)***.

Blue Slough

The original design considerations for this project did not anticipate the potential removal of levees, as the local desire to explore it had not yet evolved into a change in floodplain management policy. Despite major channel modification, Blue Slough is an important geomorphic feature of the Yakima River floodplain. If this analysis is to consider the potential for floodplain restoration for the various project alternatives, then the potential for re-establishing Blue Slough as part of the active floodplain must be considered. If levees on the east bank were set back, then hydraulic conditions for Blue Slough would change markedly. Increased peak flow, channel migration, as well as increased backwater could result, depending on the alternative implemented. As such, it is likely that the proposed crossing of the slough will have to be expanded to accommodate more normative conditions. A flood model and backwater analysis will have to be prepared for any alternative that reconnects Blue Slough to the active floodplain. The hydraulic analysis for this element as well as any other element for alternatives that involve levee alterations should be carried out as part of a comprehensive preparation of a flood model to establish new Base Flood Elevations. Setting back levees would change hydraulic conditions to such an extent that existing analyses, BFE's, Cross sections, etc., would no longer be reliable.

After the Yakima River crossing the north alignment then crosses Blue Slough just before the existing Keyes Road. The size and type of system that will be used to convey Blue Slough under the North alignment has yet to be designed and will depend, in part, upon final flood plain analysis and permit requirements. Several options are being reviewed; from extending the proposed Yakima River Bridge over Blue Slough, to creating a separate bridge structure over Blue Slough, as well as the installation of large culverts in this area.

Blue Slough is an important side channel of the Yakima River and has shoreline jurisdiction requirements. Furthermore, the possibility of increased peak flows in Blue Slough associated with future restoration activities also warrants further consideration of the hydraulics and design of the highway crossing from a flood safety standpoint. Generally, if Blue Slough is to be considered as part of a future restoration plan, much larger peak flows through the slough must be anticipated in design considerations. Conclusions drawn from such considerations will logically trend toward increased span size for Blue Slough crossings under all of the build alternatives. For the North Alternative the main stem and Blue Slough are only about-700- feet apart. A single span approximately, 1800- feet in length would span both the Yakima River and Blue Slough

5.1.22 Potential Flood Plain Restoration/Levee Removal

The proposed alignment would require reconfiguration of the levee system along the proposed alignment. In addition the northern alignment directly bisects several parcels of private property.

A long span bridge on this alignment can only be justified if the levee system is going to be set back to restore floodplain storage and function. Restored areas should be shaped so as to mimic natural river sinuosity to the greatest extent practicable in order to gradually attenuate peak flows and restore normative storage and flow capacity functions. Following this principle, the Levee YSEG7 should begin a taper eastward away from the floodplain from a point just East of Blue Slough crossing beneath the Old Moxee Road to obtain maximum potential floodplain restoration, .the levee setback should then arc southeast along either Keyes Road or Blue Slough to SR 24. South of SR 24, the levee should arc again to the Southeast along the slough. This alignment can also accommodate moderate floodplain restoration with levee alignments along Keyes Road and the current gravel pit access road located west of Blue Slough. ***(See Figure 18 and 19)***

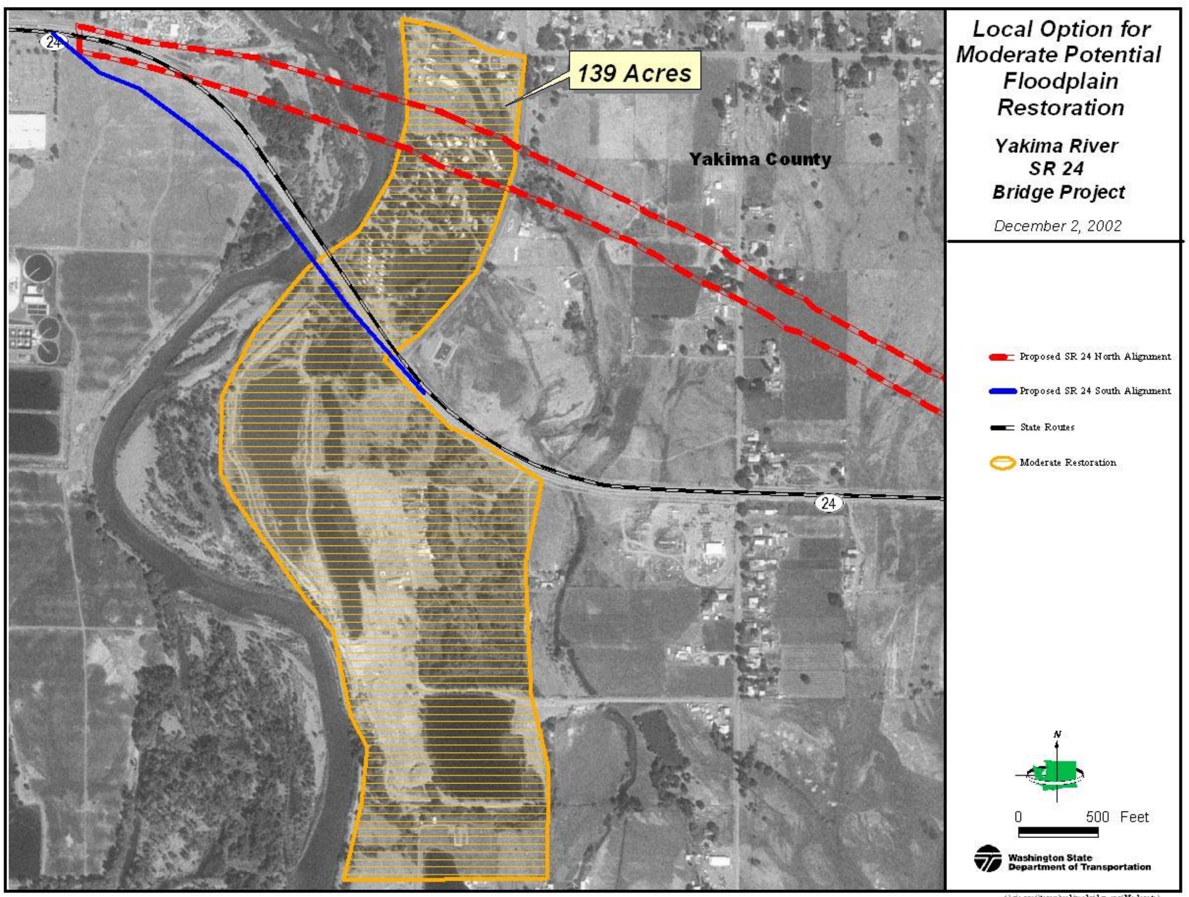


Figure 18: Alternative 4 Moderate Potential for Floodplain Restoration

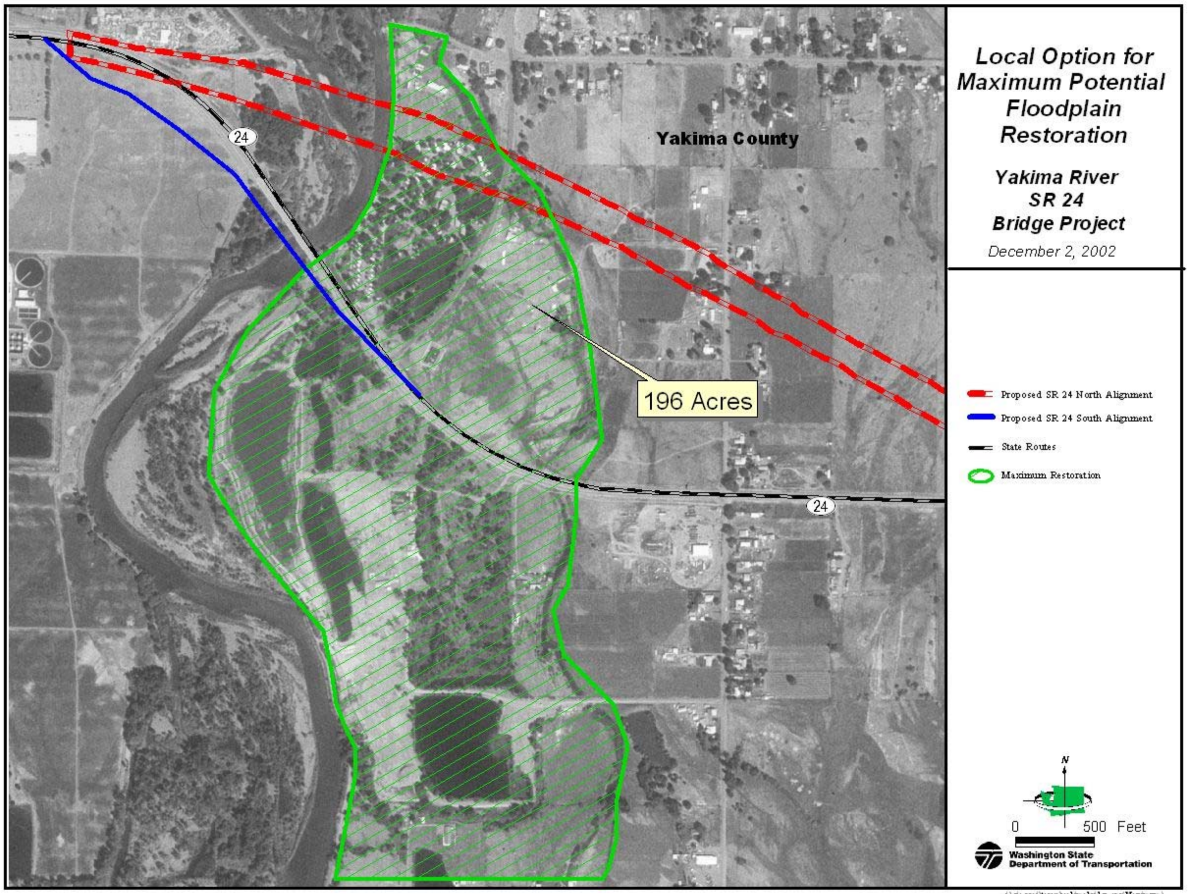


Figure 19: Alternative 4 Maximum Potential for Floodplain Restoration

5.1.23 Direct Impacts

Levee Removal

A long span on this alignment can only be justified if the levee system is going to be set back to restore floodplain storage and function. Restored areas should be shaped so as to mimic natural river sinuosity to the greatest extent practicable in order to gradually attenuate peak flows and restore normative storage and flow functions. Following this principle, the levee YSEG7 should begin a taper eastward away from the floodplain from a point near Blue Slough crossing beneath the Old Moxee Road. The levee setback should then arc southeast, along either Keyes Road or Blue Slough to SR 24. South of SR 24 The Levee should arc again to the Southeast, finally running south along either Blue Slough or the gravel pit access road.

Floodplain Acquisitions

Under this alternative, approximately 8600 linear feet of new right of way within the floodplain would be required for the new road prism. This would cause a direct impact on several parcels Total acreage for new floodplain fill would be 24.61 acres, assuming a minimum 1000-foot span bridge. A review of aerial photographs and field observations indicated that 15 to 20 structures would be directly affected by the project.

Hydrology/ Hydraulic Analysis.

A backwater analysis was prepared in 2002, for a north alternative 1000-foot bridge span (*See Appendix B*). The analysis indicated that despite using larger piers for the replacement span, a reduced number of piers would result in a slight reduction in backwater surface elevations (0.42 feet at normal annual high flow, 0.8 foot at the 100 year flow of 56,300cfs) from the existing bridge, if pier spacing recommendations in the analysis were followed. This would tend to reduce velocities and scour just below the alignment however some backwater effect will still exist, thus some bed aggradation upstream of the alignment may still be anticipated, albeit at a reduced level.

Extrapolation of this analysis to a similar span on the Southern Alignment cannot be accomplished using existing data. Additional data must be gathered to establish cross sections at the bridge site and downstream, and establish boundary hydraulic conditions as model parameters. These must be drawn from new channel cross-sections, levee profiles, as well as topographic and hydrographic data. This analysis could then become completed with new floodplain configuration being evaluated by the YCFCD.

Similarly, the long span alternatives on either alignment will need additional modeling to assess potential backwater effects. New floodplain cross-section profiles based on levee setback scenarios must be developed, with attendant boundary conditions for each alternative. A model run simulating flood conditions with setback levees must then be developed. This should be a "2D" model based on two-foot contours tied in with new channel cross-sections in order to adequately model storage and complex routing of floodwater outside of the main channel. This will indicate reliable base flood elevations for levee setback scenarios that could be applied to a backwater analysis for a long span bridge. *(See Appendix C).*

The Yakima County Flood Control District is in the process of obtaining LiDAR (Light Detecting And Ranging) topographic data that will meet the accuracy standard for this type of detailed flood modeling *(See Appendix C)*. Without reliable base flood elevations, it is not possible to model the potential backwater effect of the long span bridges under various restored conditions. As selection of these alternatives hinges in part upon the degree to which the various alternatives accommodate or preclude floodplain restoration, modeling long span bridge effects should be carried out in close cooperation with floodplain restoration modeling and planning efforts. Not only is the channel cross section markedly different if more of the historic floodplain is reconnected, but the boundary conditions under a set back levee scenario would be completely different as well.

Developing a flood model capable of simulating peak flows for levee setback scenarios is a necessary step in developing any future floodplain restoration project involving levee alteration or removal. If a long span bridge, either along the south or north alignment is selected as a preferred alternative then its backwater effects should be coordinated with overall flood modeling efforts.

This discussion has focused on backwater effects and the implications for streampower, erosion, and avulsion, because these are hallmarks of the existing constricted channel conditions, which lies at the root of the dis-equilibrium that drives the scour, erosion, and flood/avulsion risks that this project must address. In the event that the bridge is lengthened however, then the effects of increased conveyance must be addressed as well. Care must be taken so as not to convey too much additional water downstream thus worsening downstream flooding conditions. This is particularly the case south of the existing alignment where the levees cannot handle the same capacity as those upstream. This reinforces the fact that the bridge length and potential restoration of flood storage a capacity are inherently linked. Just as the bridge must be lengthened in order to accommodate floodplain restoration, additional storage must be provided if conveyance through the project area is to be increased resulting from an increased span. As with backwater effects, downstream conveyance effects on base flood elevations must be carefully modeled with storage and downstream channel capacity limitations in mind as part of any potential floodplain restoration scenario.

Fill

Under the north alternative a large amount of new fill would be required within the floodplain. If a 1000-foot span were used this new fill footprint would total 24.61 acres. Areas subject to filling under an Alternative 4 includes approximately 7.40 of wetlands *(See Wetland Biology Report for additional information).*

Erosion

5.1.24 Indirect Impacts

Please refer to discussion of levee removal under direct impacts section for this alternative

5.1.25 Cumulative Impacts

Gravel Pit Discussion

The purpose of analyzing a longer span alternative for this project is to accommodate local desires for floodplain restoration. As described in this report and elsewhere, the restoration options focus on the east bank of the Yakima River, where the population and presence of infrastructure is less dense. The area along the east bank of the river downstream from the existing alignment has been identified in work done by Stanford, Lorang and others as having the greatest potential for restoration *(Stanford, et al, 2002).* Gravel pits belonging to the WSDOT, Yakima County, and other private owners occupy this area. The potential for ecological and infrastructure damage from river avulsion into the gravel pits has been cited as a concern by County officials, prominent academic researchers who have studied the river, and WSDOT floodplain management staff. The risk here is that if the river recaptures the pit sites, then the thalweg and sediment bedload will be entrained into the pits. If a catastrophic river avulsion into the gravel pits in the lower reach were to occur it would entrain the rivers sediment load, while increasing slope and velocities into the avulsion site. The implications of this for riverine processes, infrastructure, and flood safety can be severe. Please refer to discussion of avulsion risk in section 1.

Head Cutting
The sudden increase in both channel and water surface slope that would result from an avulsion of the river into the pits would start a head cut traveling upstream as the increased water velocity drove the bedload to equalize the channel depth with that of the pit(s). This erosive process could extend for some distance upstream, threatening the stability of any levee or other structure in its path the distance of the head cut would depend upon the size of the pit and the length of time it takes for the entrained bedload to equalize the topographic difference between the channel and the pit floor *(Dunne 1976).*

A second possible outcome of river avulsion into the gravel pits would consist of increased scour downstream due to bedload entrainment. As the river avulses into the pits they quickly fill with water and start to fill with sediment. When the water reaches the top of the pit it flows overland to find a new channel or to re-enters the old one. Regardless of which, the water returns to the river much sooner than the entrained bedload, which remains entrained until the pit is filled in. The water re entering the channel is thus free of sediment. The carrying capacity of water entering the reach downstream of the avulsion is greatly increased. Thus, erosion and channel scour increase until the carrying capacity of the thalweg is again attained, or until an additional constriction dumps the sediment load in a backwater and starts the process of s bedload imbalance anew. Again the extent of this outcome would be determined at least in part by the length of time it takes to equalize the topographic difference between the river channel and the avulsion site pit floor. As with the head-cutting process, increased channel scour downstream would place all levees, bridges, irrigation headworks, and other waterfront infrastructure at greater risk for erosive damage.

Because of the potential for increased ecological damage and increased damage risk to infrastructure, if there is to be any restoration of floodplain in this vicinity then detailed (two foot contours) topographic data for both the channel and gravel pit areas must be gathered and analyzed for avulsion risk. Based upon the findings of this data the gravel pit flood elevations should be brought up to within six to eight feet of grade *(Lorang Pers Comm, Freudenthal, Pers Comm, Park, Field Obs 2002).*

Meander Belt Migration/Sewage Treatment Outfall
The constriction of the channel within the project area combined with gradient issues between the floodway and floodplain /gravel pit elevations, and the high stream power occurrences within the project area just below the existing span all point toward an anticipated tendency for the channel to migrate to the east if the levees along the east bank are removed or set back. This raises concerns with regard to the outfall for the City of Yakima Sewage Treatment Plant which discharges to the river at approximately RM 110.5. The NPDES (National Pollutant Discharge Elimination System) permit for the sewage treatment plant is predicated upon discharge into the river in an approved mixing zone in order to dilute the effluent. If the channel migrates to the east, the outfall could be left without its' mixing zone, and thus, be out of compliance with the NPDES Permit. An in depth examination of alternative outfall and treatment options must be carried out in order to develop and implement measures to address this potential before any setback of levees is attempted. Potential strategies may include selective breaching of east bank levees to allow side channels to form while keeping the thalweg entrained, moving the outfall to a different location, changing the outfall to a canal or created wetland application. Examination

of these strategies lies beyond the scope of this analysis, however it is essential that such examinations be carried out.

6.0 CONCLUSION

Alternative Comparison

The purpose of this report was to analyze the potential for floodplain restoration under the various alignments considered, and to evaluate the potential project impacts to floodplain function. While both the northern and southern long bridge alternatives can accommodate a range of bridge lengths the moderate and maximum floodplain restoration scenarios described in this analysis, distinct differences emerge when considering the comparative floodplain impacts of the alignments. These impacts fall into two areas, floodplain fill, and direct impact to private lands and structures.

Floodplain Fill

All of the Northern alignment would be placed on new floodplain fill. The total estimated footprint of new fill in the floodplain for the Northern Alignment is approximately 24.61 acres. Conversely, the Southern alignment would require only a 16.29- acre footprint of fill in the floodplain. In addition, about half of this footprint is already occupied with the existing SR 24 road prism and does not represent a new footprint, thus, the new floodplain footprint estimate for a Southern alignment with a longer span is approximately 8.15 acres. The obvious conclusion is that the impact for the Southern alignment in terms of new floodplain fill is considerably less than that of the Northern Alignment. The argument could be made that if a Northern alignment was constructed then the existing fill along the Southern alignment could be removed. While this could potentially occur, such an action would add to the cost of the project and only include removing fill where existing property access was not an issue. In addition the impact in the old right of way from years of compaction would hamper the restoration of floodplain functions such as hyporheic flow channel migration and aquifer recharge for years to come unless normative soil conditions were restored through excavation and scarification of the substrate once the fill was removed.

Impacts to Private Lands and Structures

As described in section on the Northern Alternative the proposed right-of- way goes through several parcels of private property and directly impacts at least twelve principal structures that are within the proposed right of way. An additional, five to eight structures may also be affected due to close proximity to the proposed right of way.

By comparison, the Southern Alternatives have little to no direct impact on existing private structures, because it follows the existing right- of- way, which can be expanded into currently unoccupied areas of the floodplain. Thus the socioeconomic impacts, hardships, and controversy associated with condemnation of directly impacted private property is largely avoided.

Restoration Opportunities

With regard to potential floodplain restoration, a longer (1200-2200 foot) span on either a Northern or Southern Alignment can facilitate either a moderate to maximum future restoration scenario Lead by other local governments and agencies that have the authority to undertake such action. Because of its location in the middle of the sub-basin the reaches encompassing the project area form a lynch pin in terms of potential floodplain restoration. Lengthening the SR 24 span to accommodate floodplain restoration removes a bottleneck that allows the direct restoration of nearly two hundred acres of floodplain. In addition opening up the reaches in the project area facilitates the restoration of many times that acreage both upstream and downstream of the project area. Because the project area is centrally located conditions here reverberate throughout the sub-basin. As such, rectifying degraded floodplain processes (sediment transport, hyporheic flow, cut and fill alluvial channel formation, water and sediment storage etc) in the project area is an essential element of any overall effort to restore floodplain functions in the Union Gap sub-basin

<u>Short, Moderate, Long Span Ranges</u>

The Pro's and Con's

6.1.1 <u>Introduction: Range of Floodplain Accommodation</u>

In considering future options for potential restoration of the Yakima River floodplain the key factor is of course the location of the levee system. This determines the size of the channel migration zone the amount of flood storage provided as well as the potential for the creation of connected habitat. As the SR 24 Bridge must span the area of the floodplain encompassed by the levees (the floodway) the location of the levees is a key determinant for the proposed bridge length. Generally, the wider apart the levees are set, the longer the bridge must be in order to span the floodway. This analysis has identified two geomorphic and topographic features that present logical alternatives for levee setback location on the east bank of the river A levee set back to Keyes Road would accommodate a moderate level of floodplain restoration. It has the advantage of utilizing an existing road grade. In addition a setback along this delineation would closely coincide with setback levees proposed by the Central Premix Company for the proposed East Valley Gravel Mine (*David Brown and Associates 2002*). A levee setback to the east bank of Blue Slough would accommodate the maximum potential floodplain restoration without impacting the more populated area Southeast of the project area along Riverside Road. It has the advantage of utilizing the existing geomorphic channel pattern of the Slough to help set a more stable floodplain boundary. In addition, a levee setback along this delineation would allow the restoration of Blue Slough as part of the active floodplain which would greatly improve habitat.

6.1.2 <u>Short Span Bridge</u>

[Approximately 800 to 1000- feet] The obvious advantage of a shorter span is in cost. However a short span precludes most (if not all) potential floodplain restoration. As a key criteria for this analysis is the degree to which a given alternative does or does not preclude floodplain restoration a short span alternative would not be a preferred option as it would reinforce the current channel constriction that has been shown to be at the root of the environmental and flood risk problems. Backwater and scour effects would continue, as would the dis-equilibrium in bedload transport both between and within the reaches of the project area. Avulsion risk would continue to increase as the conditions driving it are reinforced. No improvement in flood storage is provided no improvement in hyporheic function is provided. Assuming an active channel width of three hundred feet, a span in the 800-1000- foot range only accommodates 2.6 to3.1 channel widths for potential channel migration.

6.1.3 Moderate Span Bridge

Moderate span bridge would be approximately 1200 to 1600- feet in length. A span of this range would not preclude a moderate level of floodplain restoration by allowing levee setbacks to occur on the East bank of the river. In terms of floodplain function, setting back the levees would reduce channel constriction, backwater effects, water slope and velocity, streampower, and scour. The extent of these reductions would be determined chiefly, by the length of the span and the number of piers required. These improvements in channel and hydraulic conditions will in turn reduce dis-equilibrium in bedload transport both within and between reaches. As a result avulsion risk would decrease. If floodplain restoration accommodated by a span of a moderate range involves filling in the gravel pits south of the existing alignment (which this analysis concludes would be absolutely necessary) then avulsion risk could be greatly reduced. Additional flood storage would be provided and these storage areas would also enhance hyporheic function. Assuming an average active channel width of three hundred feet a moderate range span would accommodate 4 to 5.3 channel widths for potential channel migration

6.1.4 Long Span Bridge

[Approximately 1600 to 2200 feet] In terms of floodplain function, setting back the levees would reduce channel constriction, backwater effects, water slope, and velocity, streampower, and scour. The extent of these reductions would be determined chiefly, by the length of the span and the number of piers required. A long span would tend to reduce erosive forces more than a moderate span. A backwater analysis would be needed to determine the particular effect of a given bridge length. *(see conclusion-modeling recommendations)*. These improvements in channel and hydraulic conditions will in turn reduce dis-equilibrium in bedload transport both within and between reaches. As a result avulsion risk would decrease. If floodplain restoration accommodated by a span of a moderate range involves filling in the gravel pits south of the existing alignment (which this analysis concludes would be absolutely necessary) then avulsion risk could be greatly reduced. Additional flood storage would be provided and these storage areas would also enhance hyporheic function. Assuming an average active channel width of three hundred feet a moderate range span would accommodate 5.3 to 7.3 channel widths for potential channel migration. Floodplain restoration Pros and Cons for each span range are summarized in **Figure 20**.

Figure 20: Restoration Potential Summary Table

Criteria	Unit	Short (800-1000')	Medium (1200-1600')	Long (1600-2200')
Cost	Rank	L	M	H
Erosive forces	Rank	H	M	L
Floodplain Storage Potential	Acres	106	139	196
Floodplain Restoration Potential	Percent	54%	72%	100%
Hyporheic Function	Rank	Min	Mod	Max
Avulsion Risk	Plus/Minus	Increased Risk	Reduced Risk	Reduced Risk
Channel Migration Opportunity	Channel Widths	2-2.6	2.6-4.6	5.3-7.3

Notes:

- Erosive Forces: Estimates the relative level of erosive force (sheer stress, stream power, velocity, etc) reduction anticipated for each span range.
- Avulsion Risk: Assumes restoration of gravel pits to grade and set back of levees on East Bank for medium and long span ranges.
- Channel Migration: Numbers represent potential restored floodplain cross- section in terms of channel width assuming a minimum average active wetted channel width of 300-feet.
- L= Low, M= Medium, H= High

6.1.5 Floodplain Restoration

This analysis has shown that with a levee setback to Keyes Road or Blue Slough essentially the same floodplain restoration potential exists for either a northern or southern long span alignments.
The main advantage of a North Alignment is that the location of the crossing would be in an area of somewhat lower stream power, thus less prone to erosion. This however is more than negated when floodplain impacts of new fill footprint, and direct impact to private residences lying within the proposed right-of-way.

The main advantage of a Southern Alignment is that it re-uses the existing right-of-way and avoids most (if not all) direct impacts to private residences and natural resources located in the floodplain. In addition it has a smaller new floodplain fill footprint and reduced wetland and other habitat impacts *(McQueary, 2002).*

If drilled shaft pilings are used (as has been proposed), and the west abutment set back to avoid the unstable bank zone identified in the "Yakima County Flood Hazard Mitigation Plan", the replacement bridge should not be affected by the greater stream power present at the southern alignment. To the contrary, it is anticipated that lengthening the span to facilitate levee setback will help alleviate the channel and water surface slope conditions that are driving stream power to such an extreme at this location.

Mitigation Recommendations

If changing the bridge length and/or alignment is done to facilitate floodplain restoration, a proportional mitigation credit should be developed and enumerated to account for environmental credits to WSDOT as a result of any bridge configuration that facilitates such restoration. This credit should account for all of the habitat specifically identified under the minimum, moderate, and maximum restoration scenarios developed for this analysis, plus a proportion of adjacent floodplain areas where restoration is facilitated due the normalization of floodplain functions within the project area. "The zones of normative function effect," would extend into the reaches both upstream and downstream of the project area that meet a "but for" test for restorative facilitation. For example, restoration of floodplain upstream of the site is permanently precluded if the bridge is not lengthened because of the bottleneck that the short span imposes on the river channel. Therefore, a proportional credit for future restoration in the reach upstream of the project should accrue to WSDOT to offset efforts to facilitate such restoration through lengthening the bridge.

As described in this report, the Yakima functions as a shifting mosaic of interdependent habitat types (wetlands, active channel; side channel riparian, gravel bars, etc.) It can be a challenge to apply the static arithmetic of mitigation ratios based on discreet acreages for habitat type within the inherently dynamic situation of a functioning cut and fill alluvial floodplain. Development of a proportional template for shifting habitat mosaic components may be a more accurate way to quantify restored habitat values and functions and thus enumerate mitigation credits either from a functional, spatial, and/or economic metric. Given the direct and indirect habitat functions/benefits derived under the project alternatives analyzed in this report, the result of actions taken by WSDOT is that the project is self mitigating with a likely subsequent balance of credit based on the amount of credit left after direct project impacts are deducted from total credit derived from the action(s).

Recent work by Stanford, Snyder, Lorang and others has begun to identify proportional habitat components and complexity of the existing floodplain in order to establish a baseline for restorative potential in various reaches of the Yakima *(Stanford et al, 2002)*. Water and channel types and channel complexity for the Union Gap Reach are summarized in **Figure 21**. The data presented identifies the spatial and proportional extent of surface water habitats and islands based on type and connectivity. A combination of airborne remote sensing, field verification, and survey information offers a potential system for accurate, consistent, and efficient regional assessments of habitat characteristics within large dynamic riverine systems. (*Stanford et al 2002*). Study results can then be compared with data taken from historical photographs and other data sources, or developed from examination of normative floodplains on rivers that share cut and fill and gradient characteristics, but do not have the level of human intervention exhibited on the Yakima. In order to accomplish this, additional remote sensing data delineating the extent of riparian zones and wetlands should be developed and added to the existing data on water bodies to present an over all picture of the existing habitat mosaic. In addition, the stream power, sediment budget, and restorative potential research carried out by Stanford, Lorang, and others should be revisited and augmented with new LiDAR data to increase the accuracy of this already excellent analysis of restorative potential. Results of this work should be used as a core component in developing any floodplain restoration scenario.

Figure 21: Water and channel types and channel complexity measures for Union Gap reaches, Yakima River

Water body type	Number	Area (ha)	% of all water
Main Channel	3	69.21	46
Islands within main channel	58	56.33	
Floodplain ponds	14	0.38	<1
Connected off channel habitat	23	3.73	3
Disconnected off channel habitat	219	13.84	9
Gravel ponds	34	56.37	38
Islands within ponds/back channels	25	0.57	
Other open water	45	5.53	4

Channel Type	Length (km)
Main channel	9.65
Secondary connected channels	10.63
Back channels	6.19

Channel complexity	Number
Separations	49
Returns	46
Backwater separation	58
# of separations per river km	5.08
# of returns per river km	4.77
# of back ch. separations per river km	6.01

Immediately South of the existing SR 24 right-of-way, WSDOT owns a gravel pit site (DNR permit #70 011151, pit site PS-E-187) the 15-acre site has been partially excavated to a depth of approximately 7 feet. While the DNR permit file for this site indicates that no naturally occurring wetlands are present at the site, its location within the floodplain makes it an excellent candidate for potential wetland creation for mitigation purposes, particularly if the floodplain is restored to allow partial or complete connectivity. The structure in either the moderate or maximum bridge lengths is self-mitigating, with the potential for a net credit based on restorative conditions that would exceed impacts from construction activities.

Related Analysis

According to channel migration analysis presented in the Yakima River CFHMP, the west abutment for all alternatives under the present configurations would be located in an unstable channel zone. The bank in this location has been receding since the channel migration resulting from the 1996 flood event *(Feudenthal, Pers Comm)*. In addition, Yakima County is considering alterations of levee FED RB4 situated on the Right bank, upstream of the existing bridge location. This alteration would likely involve a setback of the levee to recapture an important side channel running through a portion of a wrecking yard just north of the existing span on the West bank of the river. In light of these risk factors, this report recommends that the bridge abutment be set back beyond the unstable zone as delineated in the CFHMP.

The constriction of the channel within the project area combined with gradient issues between the floodway and floodplain /gravel pit elevations, and the high stream power occurrences within the project area just below the existing span all point toward an anticipated tendency for the channel to migrate to the east if the levees along the east bank are removed or set back. These types of action (levee relocation) are outside the authority or propose of the WSDOT and will be dependent on other outside agencies to pursue *(Yakima County, USACE, BOR)*.

Regional Sewage Treatment Plant

Changes that may affect the Yakima River channel location would also raise concerns with regard to the outfall for the Yakima Regional Sewage Treatment Plant, which discharges to the river at approximately RM 110.5. The NPDES (National Pollutant Discharge Elimination System) permit for the sewage treatment plant is predicated upon discharge into the river in an approved mixing zone in order to dilute the effluent. If the channel migrates to the east, the outfall could be left without its' mixing zone, and thus be out of compliance with the NPDES Permit. An in depth examination of alternative outfall and treatment options must be carried out in order to develop and implement measures to address this potential before any setback of levees is attempted. Potential strategies may include selective breaching of east bank levees to allow side channels to form while keeping the thalweg entrained, moving the outfall to a different location, changing the outfall to a canal or created wetland application, or considerable additional treatment. Examination of these strategies lies beyond the scope of this analysis, however it is essential that such examinations be carried out. It is advised that WSDOE work proactively with the YFCZD and the Regional Sewer Treatment Plant to resolve this issue prior to levee movements are planned.

Hydrologic Modeling

Additional data must be gathered to establish cross sections at the bridge site and downstream, and establish boundary hydraulic conditions as model parameters. These must be drawn from new channel cross-sections, levee profiles, as well as topographic and hydrographic data. This analysis could then become completed w/new floodplain configuration being evaluated by the YCFCD. This should be done as part of a comprehensive study of the floodplain on a sub-basin scale led by local government, and involving all floodplain stakeholders. While WSDOT cannot lead such as error it must be a substantial partner.

Hydraulic/Hydrologic Analysis of Bridge Design

Similarly, the long span alternatives on either alignment will need additional modeling to assess potential backwater effects. New floodplain cross-section profiles and channel conditions data based on levee setback scenarios must be developed, with attendant boundary conditions for each alternative. A model run simulating flood conditions with setback levees must then be developed. This should be a, “2D” model based on two-foot contours tied in with new channel cross-sections in order to adequately model storage and complex routing of floodwater outside of the main channel. This will indicate reliable base flood elevations for levee setback scenarios that could be applied to a backwater analysis for short, moderate and maximum span bridges.

<u>Floodplain Management (YCFCZD)</u>
The Yakima County Flood Control District is in the process of obtaining LiDAR (Light Detecting And Ranging) topographic data that will meet the accuracy standard for this type of detailed flood modeling. *(See Appendix C WSDOT flood mapping paper)*. Without reliable base flood elevations, it is not possible to model the potential backwater effect of the long span bridges under various restored conditions. As selection of these alternatives hinges in part upon the degree to which the various alternatives accommodate or preclude floodplain restoration, modeling long span bridge effects should be carried out in close cooperation with floodplain restoration modeling and planning efforts. Not only is the channel cross section markedly different if more of the historic floodplain is reconnected, but the boundary conditions under a set back levee scenario would be completely different as well. In addition, the existing cross sections for the project area stop at the current levee locations’ future cross sections for this reach should extend well beyond the current levees to pick up elevation points in the floodplain outside the current levee system. This will be necessary for modeling the effects of potential levee setback proposals on base flood elevation for restored floodplain segments.

Developing a flood model capable of simulating peak flows for levee setback scenarios is a necessary step in developing any future floodplain restoration project involving levee alteration or removal. If a long span bridge, either along the south or north alignment is the selected alternative then its backwater effects should be coordinated with overall flood modeling efforts as part of the design process. For Model recommendations, the optimal tool is an unsteady flow model capable of simulating complex channel networks and two dimensional flow patterns on floodplains, This might be accomplished using a quasi—2D network model (MIKE 11, unsteady HEC-RAS or with a true 2-D model (FESWMS 2DH, River 2D, etc.). The true 2-D model will handle diffuse floodplain flows better, while the quasi-2D network models handle pond areas, control structures, and channels better (*See Appendix C, WSDOT Flood Mapping White Paper*).

<u>Pit Site Risk</u>
Because of the potential for increased ecological damage and damage risk to infrastructure, if there is to be any restoration of floodplain in the project vicinity, then detailed (two foot contours) topographic data for both the channel and gravel pit areas must be gathered and analyzed for avulsion risk. Based upon the findings of this data the gravel pit flood elevations should be brought up to within six to eight feet of grade *(Lorang, Pers Comm Freudenthal,Pers Comm Park, Field Obs 2002*). Lastly, a formal risk assessment of avulsion potential associated with the gravel pits must be carried out toward the end of developing a detailed plan for reducing avulsion risks by restoring the pit sites to within a safer range of grade.

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